"Environmental Geography of the Semi-arid Regions of the

Hungarian Great Plains and Arizona:

Comparative Changes for Sustainable Productivity"

by

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ABSTRACT

A comparative study of the Great Plains of Hungary and the Basin area of Phoenix, Arizona was performed. Both of these regions are experiencing increasing semi-arid conditions via the desertification process taking place in various regions across the globe. The environmental, geographical, and physical aspects are discussed and analyzed with the goal of developing new environmental policies. The main emphasis is to be placed on the fact that the key to sustainable development is proper land use.

Through analysis of the anthropogenic influences of agricultural production, urbanization, and industrialization, recommendations are given to decrease the negative effects of human influence in the wake of significant climate changes. The effects of these climate changes are predicted for each region, and recommendations presented to either prevent or reverse the ecological changes that have been induced.

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INTRODUCTION

Earth, one of the nine planets within our solar system, is 510 million square kilometers and contains a human population of 5 billion. Earth can be discussed in terms of being a system, as a system is an interrelated set of things linked by flows of energy and matter. The nature of the organization of a system can be either open or closed. Earth has characteristics of both. In terms of energy, our planet can be classified as an open system. Analogous to this lack of self-containment is the functioning of a green leaf. Water, carbon dioxide, and sunlight represent inputs of energy which effect matter (via carbohydrates) while energy outputs include oxygen and water transpiration. The Earth, energetically speaking, functions in the same manner. Solar energy enters the system and heat energy leaves the system freely, while some energy is temporarily stored in various states.

Theoretically, the amounts of energy input and energy output are ultimately equal and in a fixed amount, therefore the Earth is in a relatively steady-state equilibrium in regards to fixed, dependent events. It is when either the input is greater than the output or the output remains in a stored capacity for too long of a period of time that the dynamic equilibrium of the Earth's geosystems change. These changes tend to be gradual over time and space, but do have cumulative effects on the operation of the system. This is currently the situation in the case of increasing atmospheric and ocean temperatures, as well as in the fluctuating weather patterns that are occurring across the globe.

Earth's energy equilibrium tends to naturally be dynamic. This is due to the infusion of radiant energy that is being produced by thermonuclear reactions deep within the Sun. This energy cascades through the Earth's terrestrial systems and is transformed into other forms of energy (kinetic, potential, mechanical and chemical). At the end of the cascade, the energy is emitted back to the cold vacuum of space. However, it is when the equilibrium of this relationship becomes too dynamic that we see negative cumulative effects on the operations of the system. Physical geographers and other researchers are now intensely studying whether adjustments in equilibrium are due to natural changes or anthropogenic activities. General Circulation Models (GCM's) are providing very accurate data pertaining to Earth's energy-atmosphere-water system. According to plan, by the late 1990's at least four polar-orbiting satellites will be in place as part of the Earth Observation System (EOS). The system is designed to provide GCM's that are, in turn, designed to monitor Earth's open energy system.

Our planet is simultaneously a closed (or nearly closed) system when it comes to physical matter and resources. The only exceptions to its self-contained state is the very slow output of lightweight gases and the input of either tiny meteors or cosmic or meteoric dust. Since the Earth's beginnings, there have been no significant inputs of matter. Therefore, our natural resources are distributed in efficient and (relatively) fixed areas. For example, the water storage capacity of icebergs. However, the melting of icebergs and expansion of oceans (due to the lack of energy output and thereby accompanying temperature increases) may cause floods and even destruction of island communities. Stephen Leatherman, Director of the Laboratory for Coastal Research of the University of Maryland, U.S.A. predicts that a three-foot rise in sea level would displace 72 million people in China, 11 million in Bangladesh, and 8 million people in Egypt. According to Lewis, 25% of the world's population lives less than 1.1 meters above sea level.

This is only one example of how the change in energy equilibrium is effecting the distribution of matter -- the substance upon which energy exerts its effects. Global warming trends are producing not only the warmest years in history, but are also increasing desertification in many areas of the world.
The United Nations Conference on Desertification has produced estimates of areas subject to moderate or severe hazard of desertification. Estimates indicate that 0.5% (0.2 million square kilometers) of Europe and 11% (4.3 million square kilometers) of North and Central America are effected by desertification.

The environmental goals to be achieved on a global scale include the restructuring of viewpoints as to natural resources and the halting or reversing of policies and practices that have led to or will lead to environmental alterations. Every society needs to be educated as to the preciousness and finiteness of natural resources, as our available matter is part of a closed system and, therefore, exhaustible. For our purposes, the natural resource of freshwater will remain the focus of conservation measures. Additionally, scientists and the public alike must understand and communicate on one plane as to the influence of anthropogenic activities on the natural environment. This issue actually circles back to the vital role of the education of entire societies. If measures are not taken by the public now, the earth will not be recognizable, as we know it, three generations from now.

When enumerating the myriad of environmental challenges facing Hungary and the state of Arizona, U.S.A., it must be mentioned that these regions are experiencing an amplification in droughts and desertification. Due to the decrease or even disappearance of various aquatic bodies that supply surface water, the drought index is a serious concern for both regions. In addition to the negative effects on the agroeconomy and settlement potential, decreasing water supplies have influenced the presence of vital riparian habitats. The riparian flora and the fauna are decreasing at a significant rate in both regions, even to the point of extinction in many cases. Loss of water quality is accompanying loss of water quantity. Surface- and ground-water contamination is an increasing environmental concern involving both regions. Some contaminants are of a natural origin (for example, the arsenic contamination of groundwaters in eastern Hungary), however, the vast majority of contamination stems from anthropogenic activities. These activities are also effecting the soil quality . For example, over-fertilization (especially with fertilizers of the nitrate-type), not only allows for seepage of the agrochemical into water supplies, but also alters the soil's chemistry in such a way that the balance of soil operation systems is either altered or destroyed.

The long-term environmental and economic effects of the earth's changing climate will be discussed and analyzed in this dissertation. The Great Plain of Hungary and a valley of Arizona can be compared in many instances. Both regions have historically been the center of economy for the local populations. Approximately 50% of the population of Arizona is found in the valley, which positions it as a major economic region. Hungary has been known as the "breadbasket of Europe". This acclaimed title is due first and foremost to the high level of agricultural production of the Great Plain. Therefore, it is also an economic region. The climate of each region is similar in that the amount of precipitation received annually is below 500 mm and decreasing by the decade. Both regions are similar in their relief in that they both are positioned in a basin: the Great Plain (as well as the country entire) in the basin of the Carpathian Mountains, and Phoenix and its environs in a basin of the Basin and Range physiographic province of Arizona. Additionally, noticeable decreases in both water quality and quantity can be seen in the two regions. These conditions are predicted to advance in the future if solid, forthright and potent changes are not made in the policies and lifestyles of the region's citizens as the decreases in environmental quality are due, in large part, to anthropogenic activities.

The above-identified similarities allow us to co-analyze the two regions and propose joint and counter recommendations for sustainable future productivity. General environmental, physical and geographical information of each macroregion as a whole (Hungary and Arizona) will first be presented in this introduction, followed by detailed, specific information on the Great Plain and the central basin area of Arizona, the two "microregions" upon which we will focus.

Since it has been determined that the earth's change in climate is occurring due to human activities, and not natural variation, this writing is designed to analyze how anthropogenic activities can cease and/or change with the goal of ceasing or limiting the amount of damage that is being amassed upon the environment. In some instances, the goal is to limit a portion of the already employed methods that are leading to ecological damage. In other instances, the goal is to introduce new methods which can be employed to either halt or (preferably) begin reversing some of the detrimental effects that have been encountered. There are a myriad of environmental concerns (air quality, soil quality, water quality, et cetera) on the agendas of governments, researchers and environmental activist groups. The main theme of this dissertation is to specifically address the increasing desertification of the Great Plains of Hungary and the central basin region of Arizona, which is occurring as an effect of increasing global temperatures.

Since increasing aridity and decreasing water supply is one of the main concerns of desertification, this writing will further specifically analyze the aspects of water quality and quantity concerns in the wake of global warming. Finally, recommendations will be presented with the intent of accomplishing two main objectives. Arizona will need new and more creative methods of water resource management to meet the needs of the changing future. The analysis of Arizona (specifically the central portion that is within a valley and contains the largest percent of population in the state) will lead to recommendations that are designed to pilot to new models for management of the state's precious natural resource: water. Additionally, Hungary will need new models of water resource management in the wake of three time line events: the post-Soviet era, when Hungary is being reborn replete with its own management models; the challenge of water resource managers to meet the needs of the changing future; and, most important to national sovereignty and economic advancement, to receive acceptance into the European Economic Community. This document is written with the sincere intent that these goals will be accomplished.

HUNGARY: THE GENERAL FACTS

Hungary became established as a kingdom in 1001 A.D. Since then, the country has undergone many geographical adjustments. The size of Hungary's land mass has been adjusted through the centuries due to the political climate at any given time (Figure 1.1). Most recently, the 1920 Peace Treaty of Trianon resulted in a loss of two-thirds of Hungary's land mass. Today, Hungary occupies 1% of Europe's land area (Figure 1.2), comprising 93,000 square kilometers. According the Central Statistical Office, Hungary's population in 1996 was 10,214,000.

The General Physical Geography of Hungary

Hungary is geographically situated at 45°48' - 48°35' latitude and 16°05' - 22°58' longitude. Hungary's bordering countries (listed in order of the length of the longest border shared) are: Slovakia, Romania, Austria, Croatia, Yugoslavia, Slovenia, and Ukraine.

Topographically, Hungary lies in the deepest part of the Carpathian Basin, which is also known as the Pannonian Basin (Figure 1.3). Specifically, the country is found in the center of this basin encircled by three extensive mountain ranges: the Alps, the Carpathians, and the Dinarids. Geomorphologically, six macroregions exist in Hungary: the Foothills of the Alps, the Transdanubian Hills, the Transdanubian Mountains, the Intra-Carpathian Mountains, the Little Plain and the Great Hungarian Plain [54]. Generally, the low ridges are delineated at 130 meters above sea level, since the 200 meter contour line for qualification as a ridge could not always be drawn at their boundaries. Hill relief could not always be delineated at the 350 meter contour either, therefore, some mountain forelands extend to 550 meters above sea level. The mountains of

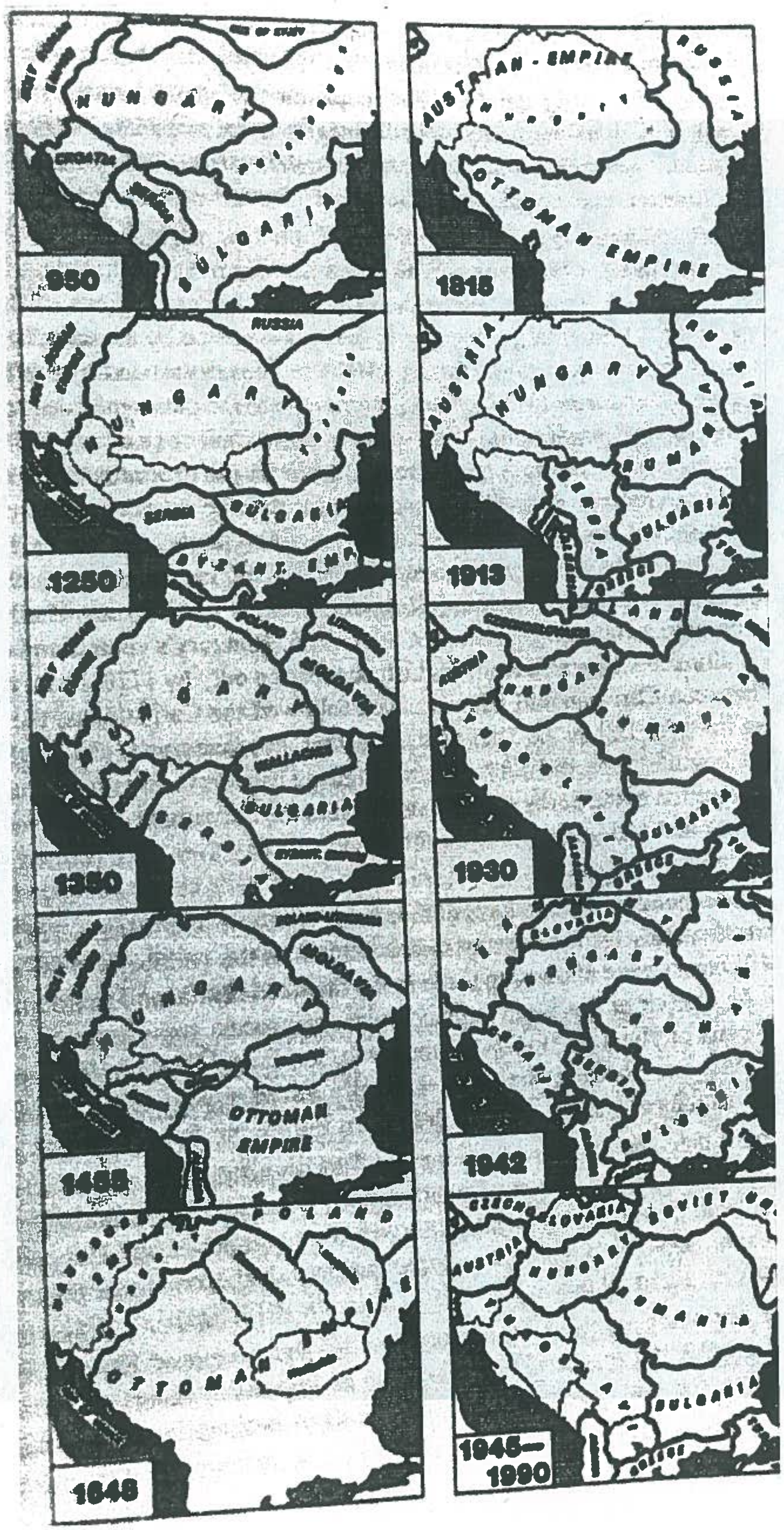


Figure 1.1: States in South Eastern Europe, 950-1990

Figure 1.2: Hungary's Present-day Position in Europe

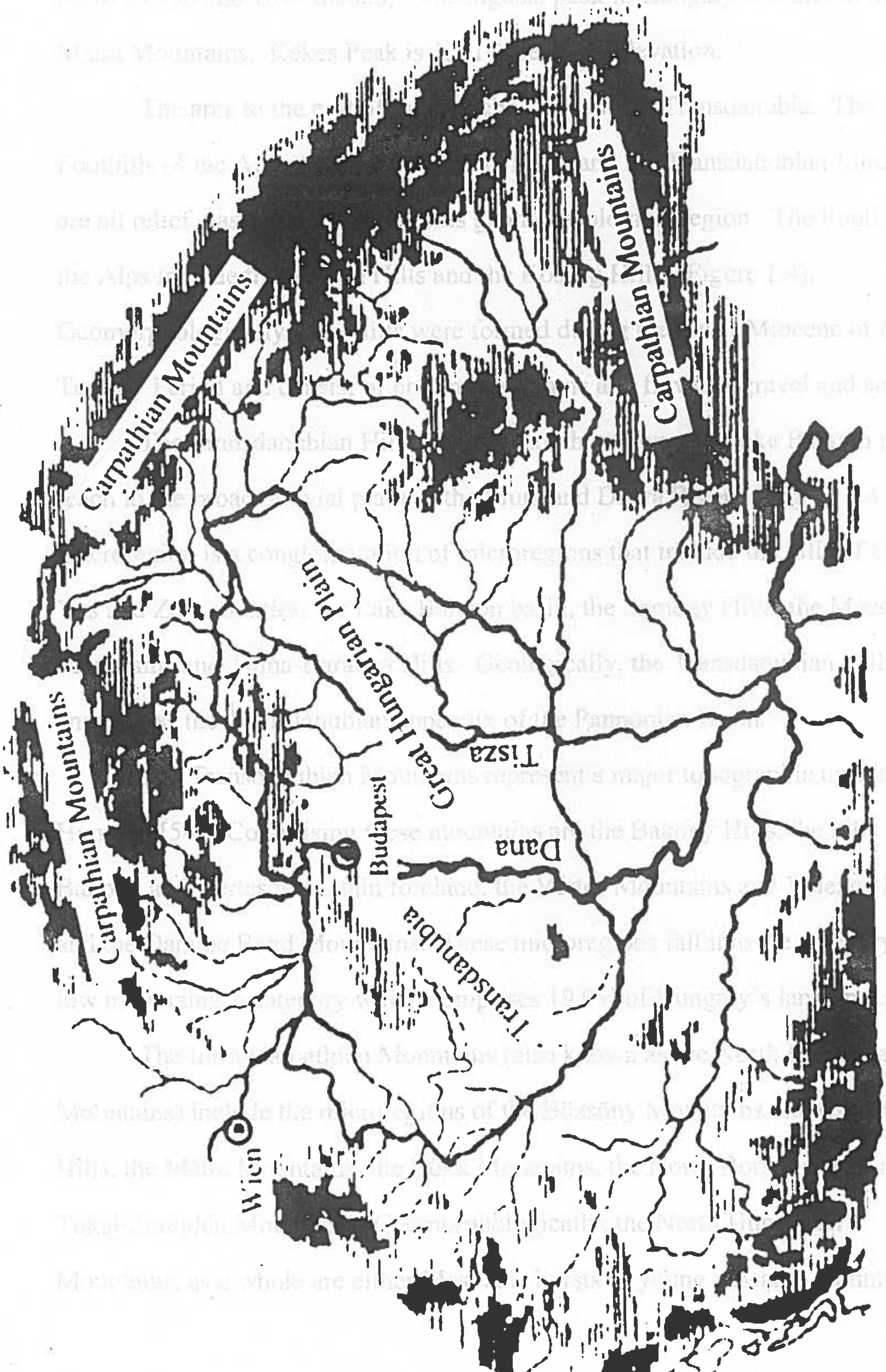


Figure 1.3: Basin Orientation of Hungary

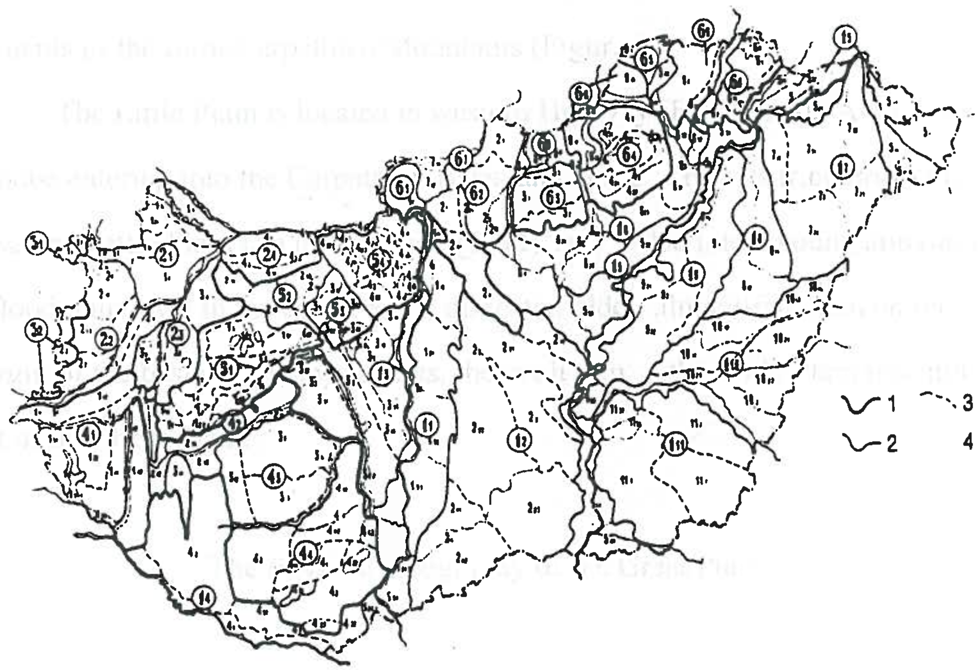
consolidated rock in Hungary can be classified as low mountains (ranging between 350 to 750 meters in elevation) and medium-height mountains (ranging between 750 and 1014 meters). The highest peak in Hungary is found in the Mátra Mountains. Kékes Peak is 1, 014 meters in elevation.

The area to the east of the Danube is known as Transdanubia. The Foothills of the Alps, the Transdanubian Hills, and the Transdanubian Mountains are all relief classes belonging to this geomorphological region. The Foothills of the Alps include the Sopron Hills and the Kőszeg Hills (Figure 1.4). Geomorphologically these hills were formed during the lower Miocene of the Tertiary Period and consist of brown coal seams and fluvatile gravel and sands.

The Transdanubian Hills lie to the south and west of Lake Balaton and reach to the broad alluvial plain of the Mura and Dráva Rivers (Figure 1.4). This macroregion is a conglomeration of microregions that include the hills of Upper Vas and Zala counties, the Lake Balaton basin, the Somogy Hills, the Mecsek Mountains and Tolna-Baranya Hills. Geologically, the Transdanubian Hills encompass the Transdanubian appendix of the Pannonian Basin.

The Transdanubian Mountains represent a major topographic unit in Hungary [54]. Comprising these mountains are the Bakony Hills, the hills in the Bakony and Vértes Mountain foreland, the Vértes Mountains and Velence Hills, and the Danube Bend Mountains. These microregions fall into the category of low mountains, a category which comprises 19.9% of Hungary's land area.

The Intra-Carpathian Mountains (also known as the North Hungarian Mountains) include the microregions of the Bözsöny Mountains, the Cserhàt Hills, the Màtra Mountains, the Bükk Mountains, the North Borsod Karst, and the Tokaj-Zemplén Mountains. Geomorphologically, the North Hungarian Mountains, as a whole are either Mesozoic horsts or young volcanic mountains.



1 = Great Hungarian Plain;
1.1 = Danubian Plain; 1.2 = Danube-Tisza Interfluve; 1.3 = Mezőföld Plain; 1.4 = Dráva Plain and plain of Inner Somogy; 1.5 = Tisza Plain; 1.6 = Northern Great Plain alluvial-fan plain; 1.7 = Nyírség sand region; 1.8 = Hajdúság loess plain; 1.9 = Nagykunság-Hortobágy alluvial plain; 1.10 = Berettyó- Triple Körös floodplain; 1.11 = Maros alluvial-fan plain; 2 = Little Plain; 2.1 = Győr Basin floodplain; 2.2 = alluvial-fan plain of Sopron and Vas counties; 2.3 = Marcal Basin; 3 = Foothills of the Alps; 3.1 = Sopron Hills; 3.2 = Kőszeg Hills, Vas county piedmont surface; 4 = Transdanubian Hills; 4.1 = hills of Upper Vas and Zala counties; 4.2 = Lake Balaton Basin; 4.3 = Somogy Hills; 4.4 = Mecsek Mountains and Tolna-Baranya Hills; 5 = Transdanubian Mountains; 5.1 = Bakony Mountains; 5.2 = hills in the Bakony and Vértes mountain foreland; 5.3 = Vértes Mountains and Velence Hills; 5.4 = Danube Bend Mountains; 6 = North Hungarian Mountains and intramontane basins; 6.1 = Börzsöny Mountains; 6.2 = Cserhát Hills; 6.3 = Mátra Mountains; 6.4 = Bükk Mountains; 6.5 = North Borsod Karst; 6.6 = Tokaj-Zemplén Mountains; 6.7 = Middle Ipoly Basin; 6.8 = hills between the Zagyva and Tarna rivers; 6.9 = Sajó-Hernád Basin; a = boundary of macroregions; b = boundary of mesoregions; c = boundary of subregions, d = boundary of microregions

Figure 1.4: Geomorphological Regions of Hungary

The Bükk and North Borsod Karst are the most extensive Mesozoic horsts. The volcanic elements of the North Hungarian Mountains were generally produced by Middle to Upper Miocene volcanic activity, but exhibit an age gradient, becoming younger from west to east. The Tokaj-Zemplén Mountains, the Visegrád Mountains, and the Börzsöny, Cserhàt, and Mátra Mountains are all volcanic elements of the Intra-Carpathian Mountains (Figure 1.4).

The Little Plain is located in western Hungary (Figure 1.4). Along the Danube entering into the Carpathian Basin and along one of its tributaries, the Rába, the Little Plain can be morphologically be divided into a young alluvial fan at floodplain level in the center and a dissected older alluvial-fan plain on the margin of the basin. In many aspects, the evolution of the Little Plain resembles that of the Great Plain.

The Physical Geography of the Great Plain

The eastern and south-eastern half of the country is occupied by the Great Hungarian Plain. The greatest part of the country is covered with plains; no more than 0.8% of the territory lies at elevations greater than 500 meters and only 32% consists of elevations of 200 meters. The Great Plain occupies an area of 52,000 square kilometers (Figure 1.3), an area larger than the other five macroregions taken collectively. The elevation of the Plain is generally between 78 and 178 meters. The lowest lying morphological region of the Great Plain (or *puszta*) is the youngest alluvial level which is even presently still under natural construction. The formerly active area of the Plain has been restricted by river and flood controls. Approximately 150 years ago, two-fifths of the Great Plain belonged to this level, however, today the flooded area is restricted to only 6% of the ancient flooded area.

There is a great difference between the flood plains of the Tisza and those of the Danube in terms of the amount of water in the floodplain level. The loose sediments along the Danube and the Dráva Rivers contain groundwater in large quantities, which tend to be absent from the fine-grained sediments of the Tisza and of its Körös tributaries (Figure 1.5). Floods produced by a rise in the level of groundwater during wet years in the Tisza area are therefore a dangerous phenomena. Consequently, water managers have constructed approximately 4,200 kilometers of levees (the majority of which are on the Great Plain), which function in protecting approximately 2.3 million hectares of agricultural land from floods. Levee construction in Hungary not only rates first in Europe in regards to the amount of land protected (in the Netherlands, 1.4 million hectares are protected, in Italy, 0.7 million hectares and in France 0.1 million hectares of land are protected), it has also allowed for reliable agricultural advancement and infrastructure development [72]. The contrasting groundwater conditions of the Danube and the Tisza (an aspect which will be further explored in a later section) also influence soil development within the two flood plains.

This macroregion is more uniform both for its evolution and its morphology than any other region in Hungary. It is a true plain, formed by the accumulation of Pleistocene and recent fluvial and eolian deposits. The basin basement is a system of buried ranges of parallel, southwest to northeast strike and Paleozoic to Mesozoic rocks. The Paleozoic includes gneiss, clay shales and mica-schists. In contrast, the Mesozoic largely consists of dolomites, limestones and clay marls.

The basement is shattered, with buried horsts, small basins, and deep depressions dissecting its surface. This fundamental relief of the Great Plains

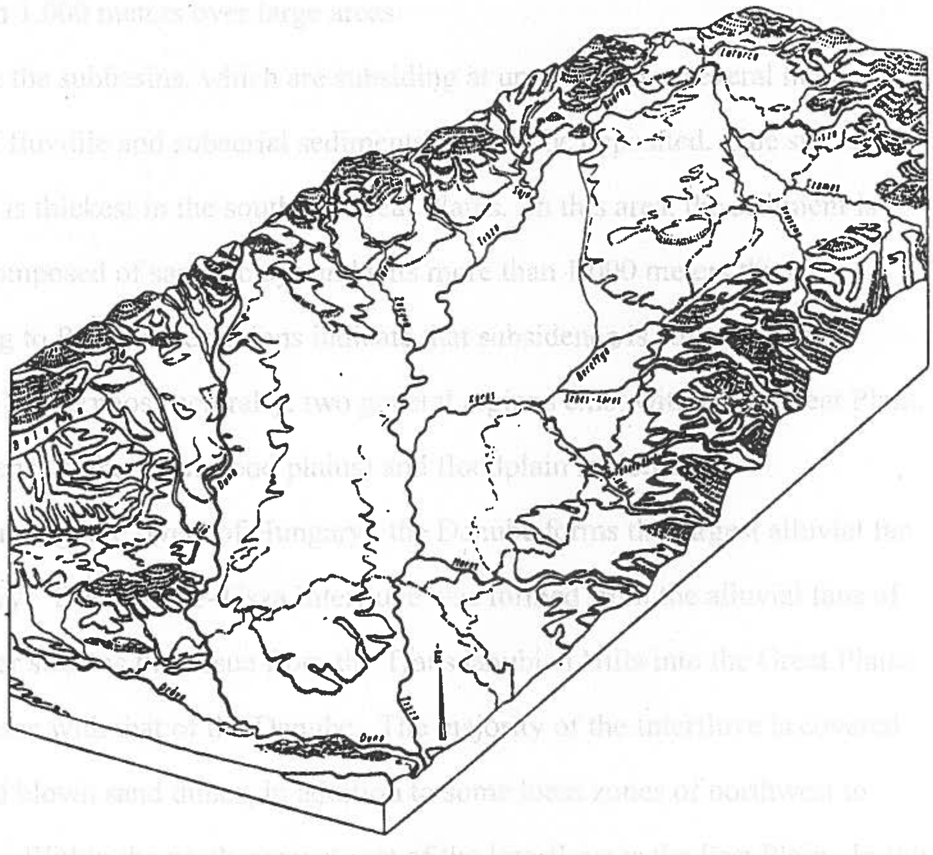


Figure 1.5: The Great Hungarian Plains

formed a portion of the continental relief from the Eocene to the Miocene. Subsidence and relief inversion started in the Neogene and intensified in the Upper Miocene (Pannonian). Subsidence in the center is evidenced by Pannonian deposits directly overlying the crystalline basement in places. The rate of subsidence may be inferred from the thickness of the clay, marl and sand sequence of the shallow Pannonian sea, which locally exceeds 3,000 meters and is more than 1,000 meters over large areas.

In the subbasins, which are subsiding at unequal rates, several hundred meters of fluvitile and subaerial sediments came to be deposited. The subaerial sequence is thickest in the southern Great Plains. In this area, the sediment is largely composed of sands, clays and silts more than 1,000 meters thick. According to Pécsi, observations indicate that subsidence is still occurring today [54]. Morphostructurally, two general regions exist within the Great Plain, alluvial fans (higher than flood plains) and floodplain regions.

Among the rivers of Hungary , the Danube forms the largest alluvial fan in Hungary. The Danube-Tisza Interfluve was formed from the alluvial fans of the smaller streams that issue from the Transdanubian Hills into the Great Plains and coalesce with that of the Danube. The majority of the Interfluve is covered with wind blown sand dunes, in addition to some loess zones of northwest to southeast. Within the northernmost part of the Interfluve is the Pest Plain. In this microregion of the Great Plain, one would find gravels and sands, as well as alluvial-fan terraces.

Morphologically, the Mezőföld is a portion of the Great Plains (Figure 1.4). It consists of alluvial-fan zones of southeastern alignment with ridges of loess intercalated between them. Both types overlie Pannonian clay and sand. The Nyírség is a large alluvial fan of the Tisza and its tributaries in the northeast corner of the Great Plain. In the eastern, most extensive portion, the fluvatile deposits are overlain by a thick cover of windblown sand. The central part of the Nyírség is also covered with wind-blown sand, but its surface is dissected by a number of valleys between asymmetric elongated parabolic dunes. In the west, the dunes are covered by a thin mantle of loess, which gradually thickens to the west.

The alluvial fan of the Maros River is located in the southeastern part of the Great Plains and rises only slightly above the present-day flood plains. The main body of the fan consists of sands and gravels, with an overlying thin blanket of floodplain loess loam or sand loam. The flat surface of this area is diversified only by a few abandoned river channels and oxbows. Since the sands and gravels of the alluvial fan are close to the surface, groundwater is high and the loess loam over the alluvia has been altered into alkali soils in some places. However, the typical soils are chernozems of high fertility.

The floodplain of the Danube in the Great Plains (Figure 1.4) stretches between Budapest and the southern border of Hungary. It is a region distinct from neighboring regions, is 200 kilometers long and in some areas up to 30 kilometers wide. Before the induction of large-scale river regulations in the 19th Century, it had been a contiguous marsh or swamp. The most typical morphostructural features are oxbows and river-bank dunes. Among the natural levees, there are shallow isolated alkali depressions. The depressions behind the natural levees farther away from the Danube bed became swampy in the cool Atlantic phase of the Holocene and substantial amounts of peat formed in them. After the induction of river regulations, the depressions of the meanders and oxbows became dry in almost every location. According to Pécsi, the formerly waterlogged floodplain was also drained and replaced by arable land, thereby protected by man-made levees [54].

In the Tisza Plain (Figure 1.4), the Tisza roamed a vast area prior to the 19th Century river regulations. During floods, the river inundated its floodplain. When the floods were over, large waterlogged areas remained in the deeper parts of the floodplain. Along the entire length of the river, there are natural levees, riverbank dunes, and higher floodplain levels which are usually covered by infusion loess.

The very flat Hortobágy steppe is characterized by alkali soils. The lower-lying portions are used as mown meadows and pastures. The meadow soils of the higher floodplain have been converted into arable land. The Nagykunság-Hortobágy alluvial plain lies a few meters above the Tisza floodplain and is predominantly covered by a thin blanket of infusion loess.

The alluvial plain of the Berettyó and Körös Rivers (Figure 1.4) is a vast floodplain that penetrates to the interior of the Great Plain. It consists of a system of coalesced alluvial fans, whose base is mainly sand covered with alluvial clayey loess. Deeper-lying back swamps and peat bogs developed among the alluvial fans built by river branches. Prior to human intervention, the alluvial silts, deposited by meandering streams, raised the level of the river beds and banks. The natural levees enclosed small undrained back swamps. Due to inundation during flooding, the latter retained some of the flood discharge in their small alkali and salt lakes. During the dry summers, their waters evaporated and alkali soils formed. The landscape was transformed by these drainage measures. The former swamps became, and still are, arable land or pastures. Other common landscape elements are flood-control dykes and irrigation canals. This is only one of the many examples of how anthropogenic activities have altered the state of the Great Plain. One would consider these positive transformations, however, human intervention has most recently crossed the fine environmental line of altering natural environs for human benefit to altering natural environs that result in negative effects on the human population. The decrease in water quality and quantity is a result of the latter.

The General Climate of Hungary

Due to Hungary's geographical location, the three main climatological zones of Europe, the Mediterranean, the Atlantic, and the continental of the Eastern European Plains, overlap in Hungary. The characteristics of all three zones can be seen in Hungary, however, the continental influence predominates. This is reflected in the cold winters and dry, hot summers, with accompanying frequent droughts. Being situated in the middle latitudes, Hungary lies in the middle of the Northern Temperate Climatic Zone. Throughout the country, there is a rhythmic change of the four seasons.

The Atlantic Ocean lies approximately 1,200 kilometers west of Hungary. Therefore, the precipitation from moisture-laden western air masses is far more irregular than in Western Europe. There is even a marked climatological difference between the eastern and western parts of the country. Transdanubia receives more precipitation than the Great Plains and the temperatures on the Great Plains are more extreme than those in Transdanubia. Hungary is not far enough from the Atlantic to have a strictly continental domination. The Adriatic and Mediterrean Seas (300 to 700 kilometers, respectively, from Hungary) also have a tempering influence on the climate, especially in the southwestern portion of the country.

High-pressure continental air masses often enter the country from the northeast and east. Over the vast expanse of the Eastern European Plains high-pressure air masses frequently develop. These air masses are characteristically cold and dry in the winter and hot and dry in the summer. If these air masses enter from beyond the Carpathians, the winter in Hungary becomes long and cold and the summer extremely hot with several weeks of drought.

Hungary's climate is influenced and modified (to a lesser degree) by relief and particularly by the country's position in the middle of the basin. The frame of mountains (the Alps, the Carpathians, and the Dinarids) surrounding the basin frequently modify and intensify the direction of entering air currents. The dominant wind in Europe is from the west. The chain of the Alps often diverts or temporarily or completely suppresses the moisture-laden west winds. If they are let through, they have often lost the majority of their moisture before entering the basin. The Carpathians usually protect the country against the cold air currents from the Arctic in the winter. In the summer they divert the hot and dry east wind that develops over Romania and Ukraine.

Within the territory of Hungary, the local climatic differences are mainly due to relief. Although there are no high mountains, even the low mountain ranges can cause considerable climatic differences between Hungary's various regions. Relief is not the only factor modifying the climate. The quality of the soil or rocks, the native flora, and the level of agricultural production all play a role in determining the climate.

Due to the continental character of the climate, Hungary receives more and stronger solar radiation than do Western European countries at the same latitude. The number of sunny hours may range from 1, 700 to 2, 100 hours annually. The maximum amount of sunshine is received in the Great Plain, where it reaches 2, 000 to 2, 100 hours per year. Sunshine is most abundant in July and

August; the period when droughts of several weeks' duration most frequently occur.

The temperature over Hungary shows no great regional differences in regards to the annual mean of 8 - 11°C. The coldest month is January (0 - 4°C), and the coldest region is the northeast due to the cold winter air masses arriving from the east and the north. The mean summer temperature in July varies between 18 and 23°C. In the summer, the eastern part of the country is hotter due to the easterly continental winds that usually carry extremely hot air. The annual absolute temperature variation is 70°C.

The direction, strength and frequency of the winds also play an important role in controlling Hungary's climate. Over the Little Plain, the greater part of Transdanubia, and between the Danube and the Tisza, the dominant winds are northwesterly. Beyond the Tisza, the dominant winds are northeasterly. In the area of the North Hungarian Mountains, the most frequent direction of wind is varied by local relief features, but is for the most part, northerly. Since Hungary is located in a basin, it is a general rule that the winds blow from the mountains toward the interior of the country.

There are also variations in the yearly rhythm of the wind directions. In the summer, the northwest wind becomes more prevalent throughout the country. In the winter, the influx of the dry, cold continental air masses causes the east and northeast winds to gain strength. The westerly and northerly winds are not only the most frequent, but also the strongest.

From an economic perspective, precipitation is the most important climatic factor. Agriculture plays a leading role in the economic structure of the country. In the plains of the country, the climate shows a frequent tendency toward drought; in other words, the rainfall during the period of vegetation is frequently insufficient to satisfy the water demands of the crops. From April until September, the average precipitation for the country as a whole is adequate for the agricultural demands. If this level of precipitation were evenly distributed across the country, there would be enough to provide for crop cultivation. However, precipitation is higher in the western portion of the country (600 to 800 mm) than in the eastern portion (500 to 600 mm). Precipitation is lowest in the Great Plain. There are areas on the Tisza where precipitation has not reached 500 mm in some years.

Precipitation becomes gradually more abundant at the margin of the plains and shows a strong and fairly regular increase with the height above sea level. The annual average precipitation in the Hungarian Mountains is 700 to 800 mm. The greatest precipitation, however, occurs in the Transdanubian Mountains which lie in the path of moisture-laden oceanic air masses. The maxima of precipitation is at the end of spring (in May) and at the beginning of summer (in June). This is due to the cyclones from the Atlantic. The second maximum of precipitation is in October due to the influence of the Mediterranean climate. The minimum amount of precipitation occurs in January and February. Climatologists believe this is due to the winter monsoon.

The Climate of the Great Plains

Just as there are three main climatological zones overlapping in Hungary, there are also three extreme climatic types that can be distinguished in the Great Plain. The three types can be represented by the environments of Szeged, Kisvárda, and Barcs (Figure 1.6), which climatically change proportionately to the distance between the regions. The Szeged region, located in the southeast of the

Figure 1.6: Political Map of Hungary

Plain, expresses the highest climatic values. This region shows 2, 102 mean hours of annual sunshine, an annual mean temperature of 11.5°C, and an average maximum temperature of 36°C. The total number of summer days averages 94, the number of hot days averages 31, and the total annual heat has been recorded at 4,344°C. The duration of potential evaporation and frost-free period averages 213 days annually, hence the Szeged region has the latest first snow and the earliest last snow than anywhere else in the Great Plain.

In contrast to the aridity of the Szeged region, the Barcs (located in the southwest part of the Plain) region experiences an air humidity average of 78% and an average annual precipitation of 774 mm. The number of annual sunshine hours is 1,906. The annual average water deficit is lower here than in any other region, it has registered at 50 mm. The annual fluctuations in monthly temperatures are also at a minimum recorded at only 21.8°C.

The Kisvárda region represents the third climatic type of the Great Plain. Kisvárda is located in the northeastern part of the Plain. The average maximum temperature is 34°C, with an annual mean temperature of 9.3°C. Total annual heat has been recorded at 3,748°C. The number of winter days is usually 38 and the number of days with frost is 118. The duration of snow cover (December 5 through March 5) and the number of days with snow (26) are at a maximum in this region of the Plain.

Therefore, the southeastern portion of the Plain represents the maximum temperatures, the northeastern portion, the minimum temperatures, and the southwestern portion, the maximum humidity values. It is logical that the southwestern portion would have the most favorable climatic position and would be the leading region in terms of moisture supply. It is this region that is situated closest to the wind directions carrying moist air masses from the Atlantic Ocean.

Additionally, there are no hills to shelter the region from wind directions.

In contrast, the southeastern Great Plain is nearest to the Mediterranean climatic region. It is frequently subjected to Mediterranean air masses from the south, southwest and southeast. The northeastern portion of the Plain is influenced longest by the Eastern European anticyclone during the winter. In regards to climatic extremes and aridity, the Jászság and Central Tisza region would be considered to have the most adverse climate.

The territorial distribution of climatic elements which are described above are governed by the action centers and the fact that Hungary is located in a basin. The Central Tisza region is the farthest from each type of action center, and therefore possesses nothing that would prevent the area from experiencing temperature trends of the northeast in the winter and of the southeast in the summer. Drought is also a feature of this region due to the rainshadow effect of the nearby hills.

The Great Plain can be qualitatively divided into four weather types based on analysis of annual temperature and precipitation data. These weather types are warm-dry submediterranean, mild-humid subatlantic, cool-humid subpolar, and cool-dry subcontinental. Over the course of a fifty year study (1901 - 1950) it was determined that the submediterranean type predominates [62]. Overall, the Great Plain is known for a moderately warm and dry character. However, the distribution of temperature is much more uniform than that of precipitation.

Since the Great Plain is situated in a climatic zone predisposed to drought, the recent increase in global temperatures will most probably cause Hungary's drought index to increase in the future. From an agricultural point of view (a major economic concern of the Great Plain productivity), mild-humid years are assumed to be favorable, whereas warm-dry and cold-dry years are unfavorable.

Experts agree that increasing global temperatures will continue to produce increasing warm and dry characteristics in the future. This would give rise to not only ecological difficulties on the Great Plain, but in turn, economic difficulties as well.

The Soils of Hungary

One of Hungary's most valuable natural resources is her varied and very fertile soil cover. The intermediate climate of the country, as well as the sum total of the varied hydrographic, geological and relief features are the factors that allow for the great diversity of the types. The soil types of Hungary can be divided into six genetical groups: Skeletal soils, examples of which are alluvial soil, wind-blown sand, and slightly humic sand; forest soils of which there is fallow forest soil, brown forest soil, rust-brown forest soil, rendzina, grey forest soils of the Mátra and Bükk foothills, and Steppe soil of forest character; meadow soils, of which there is meadow soil and meadow soil with alkali subsoil; steppe soils, of which there is steppe soil and steppe soil with alkali subsoil; alkali soils, which are either limeless alkali soil, limy alkali soil or limy-salty alkali soil; and swamp soils, which are either mucks or peaty swamp soils.

Of the skeletal soils, the alluvial soils cover a vast area. The so-called "recent alluvial soils" have very little humus associated with them. Depending on the grade of the river, the alluvial soils may be sandy or clayey. The alluvial soils of the Danube are generally limy, while those of the Tisza are deficient in lime. The sandy soils also occupy a large area (particularly in the Great Plains). The two sub-types of sandy soils can be easily distinguished. The wind-blown sands constitute loose, amorphous sand soils that are often still shifting due to the fact that their profiles reveal no real stratification. The humic sand soil has already been humidified in the first 20 to 40 centimeters due to the influence of vegetation and cultivation.

Within the forest soil type, the fallow forest soil is a podzol that was formed under the closed forests in the hills and mountains of Transdanubia (the areas with the most abundant precipitation). Within the eluvial horizon (30-40 centimeters) the humus of these soils is usually very thin and there is a strongly acid podzol top soil. This soil type is characteristic of the Intra-Carpathian Mountains and the foothills of the Alps. Brown forest soil predominates as the forest soil type in Hungary. This soil develops mainly on loess and volcanic rocks and to a lesser extent on clayey, marley bedrock, and displays a slightly acidic character. Brown forest soils cover a great part of the Intra-Carpathian Mountains, as well as those of Transdanubian Mountains and in western and southern Transdanubia.

Rust-brown forest soils are similar to the Brown Forest soil, except that the humus and illuvial layers are thicker than the Brown Forest soils. Geographically, this soil type is most extensive in the Nyírség District, Transdanubia, on the ridges of Somogy, and on the hills of Gödöllő. Rendzina is related to the steppe soils in many ways. It either occurs on its own or alternating with Brown Forest soils. Its fertility value is low, in that it dries out easily. Its pH is from slightly acidic to neutral. It is found in Transdanubia and the Intra-Carpathian Mountains.

The foothills of the Mátra and Bükk contain a soil that is intermediate between forest soils and field soils. At the southern foot of the range, there is a layer of loam that is several meters thick. A characteristic feature of the soil of the Mátra and Bükk foothills is a rich humic black or dark brownish-grey layer that is approximately one meter thick with an acidic pH.

The Steppe soil of forest character also belongs to an intermediate type. It was once a Brown Forest soil, but shifted towards a Steppe soil by either a change in natural conditions or centuries of agriculture. The occurrence of this type of soil is also intermediate between the mountains and the plains in the hilly country of South Transdanubia.

Meadow soils have generally developed along extensive flood areas, in silted-up river beds, larger hollows and flats, through the influence of stagnant pools of water or marsh vegetation that requires a high groundwater level and much moisture. Meadow soil contains a high concentration of organic material and has a thick layer of humus. A frequent sub-type of the Meadow soils is the Meadow soil with alkali subsoil. This soil has, at its lower limit of the humus layer, a considerable concentration of sodium. The geographical distribution of the Meadow soils is very varied. Apart from the former higher floodplain levels of rivers, they also frequently occur in the waterlogged flats between the Danube and the Tisza and among the sand dunes of Nyírség.

The Steppe soil Chenozem is the most fertile soil type in Hungary. It has evolved over great expanses of flood-free lowland loess banks and on the loess of varying thickness in the Mezőföld Plain. It is relatively rich in humus and has a pH that is mildly basic to neutral. In the Steppe soil profile, alkali subsoils are fairly frequent. The top soil of this subsoil type is of the same structure as that of the Steppe soil, however the subsoil becomes more compact so that its water economy deteriorates, and in dry years this type of soil would have the tendency to bake. Steppe soils are prevalent to the east of the Danube.

Swamp soil types are found in all parts of the country. Depending on the degree of humification of the organic matter contained by these swamp soils, two may be distinguished: mucks and peaty swamp soils. In the former, the organic constituents are completely humified. The largest areas of muck soils are found in the Great Plains to the east of the Tisza. These soils are also found in the swampy area south of Lake Balaton. The geographical extension of the peaty swamp soils is much the same as that of the mucks. In the peaty soils, the organic substances are humified only in the thin upper layers.

Alkali soils are found within the Great Plains region and will therefore be discussed in detail in that section. In addition to the soil types described above, several other kinds of soils occur in Hungary, but cover only lesser areas and, hence, a detailed description would not be valued within this text.

The Soils of the Great Plain

The skeletal soils of the Great Plain are blown-sands and river alluvium. Together, these subsoil types cover more than 6,000 square kilometers, or 11.6% of the Plain region. Unfortunately, the alluvium soil that is rich in inorganic mineral salts, and highly productive when drained, composes only one third of the area. The remaining two-thirds consist of the less valuable blown sands.

In areas where the sandy regions have only recently lost their natural vegetation, various types of forest soils are to be found. However, where they have long been cultivated (as in the southern half of the Plain), sandy chenozems are dominant. The zonal forest soils which develop in the moister regions of Hungary occur only infrequently in the Great Plain. Where they are found, they are representative of past natural conditions in areas marginal to the Plain. The different chernozem varieties were zonal soil types on the former, natural woody steppes as well as on the drier loess and sand surfaces of the Great Plain. Today, however, chernozems are dominant. Although numerous varieties of this soil type cover more than 40% of the Great Plain, the typical chernozem is not found anywhere. The most common chernozem is the "lime-coated type" which, together with its subvarieties, covers nearly 16% of the Great Plain. Approximately 10% of it is characterized by saline lower horizons, which must be taken into account with deeper rooted plants. This principal chernozem type covers 58% of the Bácska, 55% of the Mezőföld, and 65% of the Hajdúság. It also occurs in the Jázság, in the area between Körös and Maros, in the eastern and central part of the region between the Danube and the Tisza, and in the Central Tisza region.

The most productive soils of the sandy areas are the sandy chernozems. They comprise 31% of the table-land of the Danube-Tisza Interfluve, as well as considerable percentages of the Danube Plain south of Budapest, the Bácska, the Mezőföld and the southwestern part of the Nyírság near Debrecen. Other varieties, such as brown forest and meadow chernozems with saline lower horizon varieties are transitional in that they have not yet been transformed into zonal types. By deep cultivation, the application of lime, and the regulation of groundwater levels, these fairly productive soils can be improved. According to Somogyi, the maintenance of proper groundwater levels and constant drainage are especially important when these chernozem types possess saline lower horizons in order to prevent over-enrichment of sodium concentrations in the upper horizons [62].

The extra- or intra-zonal alkali soils are the result of the unique physical conditions of the Great Plain. Their various types occupy approximately 7,000 square kilometers or 13% of the total area of the Plain. Their nutrient content is adequate; in some cases they are very rich in inorganic minerals, however, their water economy is very poor. These alkali soils are difficult to cultivate due to their heaviness and their high concentrations of sodium salts with are often injurious to agricultural plants. Several types are categorized based on quality, concentration of sodium salts, and depth below the surface of the salt-bearing layer.

Territorially, forest steppe soils cover 40% of the well-exposed surface of the drift-slopes of the northern portion of the Great Plain and 18.7% of the Dráva Plain. They are scattered throughout the table-land of the Danube Tisza Interfluve and the Mezőföld, and are found along the Sajó (Figure 1.5). The main zone of the meadow chernozems lies between the Körös and Maros, where they compose 64% of the region.

Meadow soils are a transitional type of soil and have an association to high groundwater levels. They cover 24% of the Great Plain. The characteristic steppes of the Plain formed on these soils, following the lowering of the groundwater due to drainage. Marshy meadow soils are found among the blown sand dunes in the table-land area of the Danube-Tisza Interfluve. To a limited extent, drained and cultivated marshland and moor soils are also to be found in these regions.

Natural Vegetation of Hungary

The biotic communities of any area are determined by the distribution and delineation of the vegetation covering the region. The successive phytogeography of an area establishes "borders" that are sometimes abrupt and sometimes gradual. In either case, the ecosystems of an area are indicated by the type of plants present since their presence represents a myriad of factors such as soil types, climatic variations, elevations and topography. Therefore, a discussion on the presence and types of various ecosystems can most efficiently be conducted by discussing the geobotanical distribution of a region.

The climatic changes in Central Europe during the Tertiary Period are represented today by the Tertiary flora. This illustrates that at the beginning of the period, the climate was tropical. Fruits of the Nipa palm have been found in the lower Tertiary deposits. Following the middle Tertiary, the climate in Central Europe gradually became cooler. The tropical plants were gradually replaced first by subtropical plants and then by more temperate plants. Since Hungary's climate is transitional, the flora includes Oceanic, Mediterranean and Continental elements. Overall, the flora of Hungary belongs to the Floral region of Central Europe. This region is directly contiguous to three areas: the Subarctic region which is characterized by cool summers, cold winters, and moist climate; the Pontian, characterized by a hot and dry climate with cold winters and with steppe-like features; and the Mediterranean floral area which is warm-temperate and somewhat humid. Due to its geographical situation, the Hungarian (Pannonian) floral province is in direct contact with the eastern Pontian and southern Mediterranean floral regions.

The greater portion of Hungary belongs to the Pannonian floral province. This contains three floral zones: 1) the Hungarian Mountains, including the Transdanubian Mountains and the North Hungarian Mountains; 2) Transdanubia, including the Transdanubian Hill country and the Mecsek Mountains; and 3) the Great Plains. The characteristic features of the higher regions of the Hungarian Mountains and the less sunny northern slopes is the beech belt. On the sunny drier slopes, oak forests and oak shrub forests alternate with flowery grasslands and pastures. The Hungarian Mountains are the birthplace of Pannonian flora.

The floral zone of Transdanubia is somewhat transitional. In the forests of Transdanubia, beech and oak are the dominant trees. On the gravel hummocks of Vas County, forest pine and birch heaths occur, while on the cooler and rainier western border of Transdanubia, various mountain plants can be found.

The Vegetation of the Great Plain

The former natural vegetation of park-land and moors has for the most part been replaced by the "puszta", or plain. Forest unevenly occupies only 6.7% of the total area of the Plain. In contrast, the territorial expanse of meadow and pasture is much more even, ranging from 2.1 to 6.0% and 8 to 14% (respectively) of the cover of the Plain. If the proportions of forested areas within the individual regions is expressed in terms of the forest associations characteristic of the Great Plain, it appears that the areas of natural forest communities do not even come to close to approximating to the total extent of the forest area. This fact reflects the high degree of conscious afforestation, as well as the fact that fruit (and associated trees) are included as forest.

The park-land of the wooded steppe of the Great Plain belongs to the climatic zone of oak forests. Due to their ecosystem and topographic location, they belong to either the elm-ash-oak grove forests, which have developed from a riverine-still-water succession, or the oak forests of the higher and drier regions. Among the drought-resistant oak associations, those occurring on the Tartar-maple loess and on sandy soils are the most significant. The area of sandy oak forests includes both convallaria oak forests of moister habitat and drier heath oak forest.

The other forest types of the Great Plain are either additional elements of the grove forest type (for example elms and ashes) or are members of a transitional succession series of soft-wood groves such as willows, poplars, alder, fenwood, and juniper. The area of partly natural and completely artificial forest is also significant, of which pine forests, poplars and acacia groves exist. The hard-wood stands still occupy many areas in the Danube and Dráva Plains and Szabolcs-Szatmár-Bereg County. Soft-wood stands are also characteristic along the Danube and Dráva which are susceptible to flooding. The richest area of fenwoods are found in the Swamp region along the Danube and of the Nyírség. The Scotch fir and black pine forests are most widespread on the dry-sandy surface of the Danube-Tisza Interfluve, on the Nyírség, and in the southern part of the Mezőföld.

The most extensive forest type consists of the *Acacia* stands which comprise more than 23% of the total forest area (more than 75,000 hectares). This genus is relatively new on the Great Plain and has acclimatized well to the dryness of the region. Regionally, the drier regions, such the Danube-Tisza Interfluve, the Nyírség, and the Bácska are leading acacia areas.

The territorial expanse of the moor-marsh association has greatly decreased; less than 0.3% of the Great Plain is covered with reeds. The major expanses are found along the Danube, at Lake Velence on the Mezőföld, and along the abandoned channels of the Tisza. Meadows and pastures comprise more than two times the area of forests in the Great Plain. Their vegetation consists mainly of semi-domesticated communities resulting from transformation of microclimates and soils, as well as from constant mowing and grazing.

The former meadows on loessic heath have been entirely replaced by plough lands. The Dráva plain contains the highest proportion of meadows (comprising 6% of this area) and the Jázság, the smallest proportion (comprising

2.1% of this area). Pastures compose approximately 13% of each microregion of the Great Plain. Their proportion is lowest on sand surfaces.

Hydrological Conditions in Hungary

Surface Waters

Due to Hungary's geographic and topographic situation virtually 100% of the waters originate from the surrounding higher portions of the Carpathian Basin. Figure 1.7 illustrates the topography and hydrography of the Danube basin. The basin is drained by three major rivers, the Danube, the Tisza and the Dráva. The Tisza and the Dráva eventually drain into the Danube beyond the Hungarian borders. The major streams originate in the neighboring countries. The waters leaving the country are conveyed via the Danube, Tisza, and the Dráva through Yugoslavia and towards the Black Sea. Due to the basin and plain character of the country, the drainage conditions are generally very poor. The slope of the rivers is extremely mild; the average slope of the Hungarian Danube is 6 centimeters kilometer^{-1} and that of the Tisza is only 2 centimeters kilometer^{-1}. Consequently, the flood waves travel at very low velocities. After snowmelts or major rains in the summer even the smallest impressions in the terrain are inundated. Continuous efforts are needed to prevent the waters from reconquering the vast area which they dominated in the past.

The two main rivers that actually flow through Hungary, the Danube and the Tisza will remain the topic of discussion since the Dráva is a right-hand tributary of the Danube, flowing along the lower southwestern border of Hungary. The Danube is largest river in Hungary and in Central Europe. Its catchment area

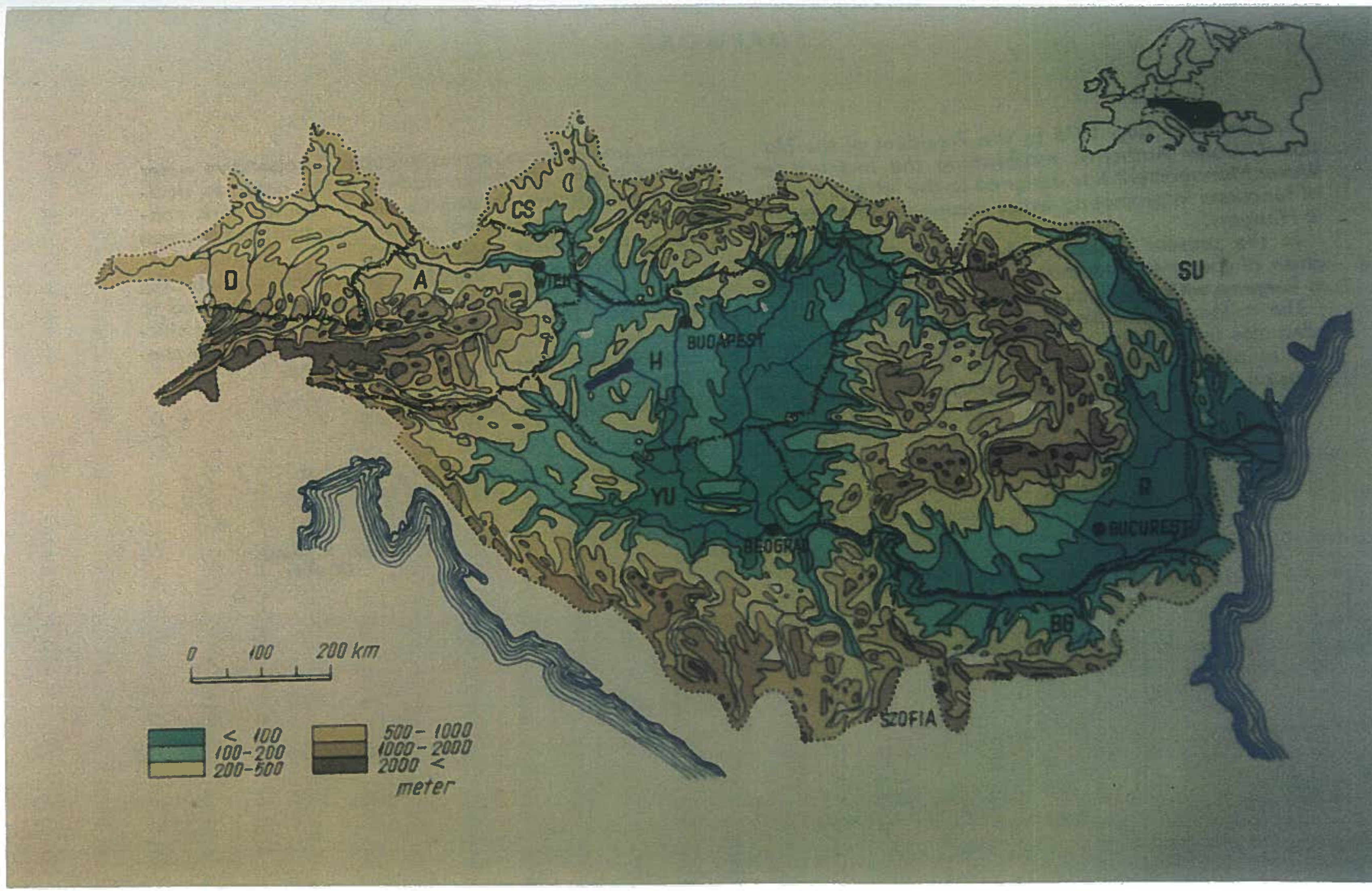


Figure 1.7: Topography and Hydrography of the Danube Basin

is approximately 800,000 square kilometers and extends over eight countries. Of its total length of 2,900 kilometers, 410 kilometers lie in Hungary. Its catchment area and length are second only to those of the Volga in Europe. The steeply sloping Upper Danube flows through German and Austrian territories. The Middle Danube begins in the Little Plains, travels through the narrower valley section of the North Hungarian Mountains, continues through a section of the Great Plains and into Yugoslavia. Therefore, Hungary is situated in the basin of the Middle Danube.

The discharge and flow of the Danube is determined by the flow of the Upper Danube and particularly of its right-bank tributaries that stem from the Alps. The annual precipitation over the catchment areas of the Danube's tributaries can range from 1,200 to 2,000 mm $year^{-1}$. Depending on the fluctuations of Alpine precipitation and on the snowmelt in the mountains, the Middle Danube has two regular floods annually, one in early spring and the other in early summer. The spring flood is not as high as the summer flood. It is caused by snowmelt in the lower regions along the upper reaches of the river. The ebb is slow and gradual because the snowmelt frequently provides recharges for a considerable period of time. Historically, the early spring floods have caused great damage in Hungary. The floods usually break-up the ice on the Danube and carry off the icefloes. This begins earlier in the upper portions of the Danube than it does in the Middle Danube. Under such conditions, the drift ice from the Upper Danube piles up in front of the cover of ice still unbroken in several regions of the Middle Danube. In this situation an "ice-plug" is formed. It was the obstruction of the river bed by an ice-plug that destroyed Buda and Pest in 1838.

The summer flood is higher than the spring flood. Therefore, it is in late June that the Danube's discharge is greatest due to the late spring and early summer rains occurring over the catchments of the Upper Danube. Additionally, snowmelt reaches the snowfields and glaciers of the higher Alpine levels around this time. The discharge of the Danube at Budapest is 600 cubic meters second^{-1} at the lowest water level and 10,000 cubic meters second^{-1} at the highest.

The Danube, however, does not freeze every year. For example, in the Budapest area, the Danube freezes only every second year. With the exception of the periods of drifting ice and of the complete freezing over of the river, the Danube is navigable throughout its Hungarian section. The Danube is of great economic importance due to its transport capabilities and to its supply of drinking and industrial waters to the settlements along its banks. Additionally, the irrigation schemes along the Danube have their water requirements met by the Danube.

The Tisza is a characteristic flatland river located in the central, deepest part of the Great Plain. The country along the Tisza possesses many interesting aspects: the vast sinuous loops, the willow groves of the flood area, the cut-off and silted-up fens and oxbow lakes, and the frequent bank dunes. These geographical aspects give the floodplain of the river a varied aspect.

Up until the river was regulated in the middle of the last century, it frequently changed its bed on its extremely wide flood area. Even though the Tisza is very changeable, it nevertheless bears a resemblance to the Danube. The Tisza also experiences two annual floods, one in early spring and the other in early summer. The water of the spring flood comes from snowmelt in the Carpathian and Transylvanian ranges. Ice-plugs do not form on the Tisza because the warm air masses from the southwest melt the ice of the lower regions before that of the upper regions. The summer flood is due exclusively to rainfall. East of Tokaj there is occasionally a second maximum of precipitation in October resulting in a third flood-wave. Its strength is attenuated as it progresses downstream.

The tributaries of the Tisza are illustrated in Figure 1.5. The most important of the right-bank tributaries is the Bodrog, a union of five rivers which joins the Tisza at Tokaj. Like the Tisza, it is a meandering, characteristically graded river. The confluence of the Bodrog and the Tisza has frequently changed as is indicated by the numerous oxbows and point bars in the vicinity of Tokaj. The Sajó receives waters from the Bódva and the Hernád before it joins the Tisza. After the Tiszafüred, the Eger is received and at Szolnok, the Zagyva carries the waters of a few smaller rivers into the Tisza. The Tisza receives no water further downstream from the tableland between the Danube and the Tisza. The eastern margin of the tableland contains only dry valleys.

The left-bank tributaries include the Szamos and Kraszna which join the Tisza near Vásárosnamémy. The Körös carries the waters of five smaller rivers into the Tisza. The river resulting by their confluence is called the Hármas-Körös. Along the banks of the Körös, irrigation is practiced over a large area. The region between the Hármas-Körös, the Berettyó, and the Hortobágy, is covered by a network of irrigation canals. Only a short section of the Maros (the largest tributary of the Tisza) flows through Hungarian territory.

The Danube, the Tisza and their tributaries flow into the plains in flat-bottomed beds with no valleys. Historically, every flood inundated vast areas paralyzing human society. The lower portions of the flood plains would be under water the majority of the year and were reed-covered marshy areas that were hardly of any economic use. Until the middle of the last century, there were approximately one million hectares of swamps along the Danube and approximately two million along the Tisza. During the second half of the last century, the development of European rail systems stimulated the grain export potential of Hungary. It was thus beneficial for Hungarian landowners to expand agriculture over as large of an area as possible. To meet the developing economic demands, the course of the Tisza, via regulation and cut-offs, was shortened from 1,400 kilometers to only 980 kilometers. The progress of the flood waters was therefore greatly accelerated and the danger of inundations significantly reduced.

The treatment of the Danube involved the cut-off of meanders and the dredging of the bed with the goal of eliminating the frequent jamming of drift ice. To prevent the inundation of the flood plains, levees were constructed along the banks of the rivers. The length of the flood levees along the Tisza is 4,000 kilometers, and those of the Middle Danube are 3,000 kilometers. Additionally, the main settlements along the banks of the Tisza are protected by circular levees against possible floods. The other aim of river conservancy regulations of the late Nineteenth Century was to eliminate the fords and shoals and therefore make navigation along the Danube and Tisza more reliable.

The largest body of standing water in Central Europe is Lake Balaton. The water surface of Lake Balaton is 600 square kilometers (Figure 1.6). On average, the lake is only 3 to 4 meters deep, except at the Tihany "pit" which is 11 meters deep. The volume of Lake Balaton (1,800 million cubic meters) is relatively small when its depth is taken into consideration. Its large surface area evaporates more water annually than can be recharged by the precipitation over the lake. The balance is restored by the Zala River and by the streams flowing into the lake along its north shore. The water level in the lake is variable, it attains its highest level in late spring and lowest level in late autumn.

One quarter of Lake Fertő (Figure 1.6), whose average surface area is 322 square kilometers, belongs to Hungary. Changes in groundwater level, evaporation, and climatic variations have a large impact on the water level of this lake. The depth of water is generally under 1 meter, and rarely rises above 1.5 meters. Other than the harvesting of reeds growing around its banks, the lake is of no economic value. The surface of Lake Velence is 27 square kilometers, 50% of which is covered with reeds. The present depth of the water is only 1 to 2 meters, which is being maintained via human efforts.

Groundwater

Groundwater came into use and gained attention with intensive agriculture in the plains and the introduction of irrigated farming. This is when groundwater prospection began in the plains and hilly regions. The groundwater table and groundwater movements were observed in more than one million dug wells and in numerous shallow and deep borings. The general rule for the position of the phreatic water table is that in areas covered with loess, its depth corresponds to the thickness of the loess. In areas of aeolian sands and in the river valleys it may reach 2 to 5 meters, and in the deeper flood plains it may be reached within 1 to 2 meters. For example, the flood plains of the Danube store vast quantities of water. North of Budapest, water is pumped from hundreds of wells that are dug in the terrace gravels.

Two types of karst water can be distinguished in Hungary: the shallow karst water having a free water table, stored in elevated limestone beds, and the karst water of deeply sunk karsted blocks. The first type of karst has no interconnected karst water table, but depends only on precipitation. The second type does not depend on precipitation, but is connected with the subsurface water circulation of the entire Hungarian basin.

Water Reserves of the Great Plain

The water supplies of the Great Plain have been a concern for a long period of time. The water supplies of the Great Plain are mainly delivered by the rivers flowing through it from neighboring macroregions which have greater precipitation. The regions on the Plain closest to the Danube and the Dráva possess the most utilizable water reserves. The water available in the northern part of the Plain is almost sufficient to meet the demands, however deficits do exist in some places (for example, at both Miskolc and Körös).

There are many subsurface water sources of the Great Plain. Certain types of subsurface water, such as groundwater, strata water, cavern water, and thermal water cannot be strictly separated because the geologic structure and evolution of the Great Plain have made their continual horizontal and vertical mixing possible. Therefore, water from precipitation, vadose or phreatic water, water from dehydration or compaction, and fossil water are all intermixed to variant degrees depending on the location and geological layer. It is not the location and origin of the subsurface water that is important as much as it is quantity and supply. Conservative calculations reveal a total subsurface water volume of 2,500 to 3,000 cubic kilometers. Some estimates of a 20,000 cubic kilometer volume might even be realistic. A great proportion of this water reserve is fossil or static. Therefore, the deeper subsurface layer is not being renewed.

Approximately two-thirds of the exploitable groundwater reserve close to the surface are found within a zone along the rivers that is maximally two kilometers wide. Therefore, there is a reliance on the shore-filtered supply of water. It is believed that much of the other groundwater is derived from precipitation. The deeper strata are replenished with groundwater via precipitation that falls outside of Hungary and moves toward the center of the Carpathian basin. It has been estimated that only 1% of the total precipitation need by kept under the surface in this way to maintain groundwater level.

The first survey summarizing the groundwater reserve of the Great Plain was published by VITUKI in 1954. The areas of the Great Plain can be ranked according to abundance of subsurface water as (which is reported as liter per second per square kilometer) as follows: the Danube Plain registers at 6.5, the Dráva Plain at 5.0, the plain of Szatmár-Bereg at 5.4 , the Bodrogköz, 2.7 and the northern part of the Great Plain at 2.1. The areas on the Great Plain with the least amount of subsurface water are: the Nyírség which has been calculated at 0.85, and the Mezőföld and Körös region which both register at 1.0. The variations in levels are produced through time and various surface types. Climate, however, has also been shown to play an important role.

ARIZONA: THE GENERAL FACTS

Arizona became a state in 1912. Prior to that, it was a territory of the United States. Humans have occupied Arizona since prehistoric times, however the "modern" anglo-saxon society did not establish itself in this region until the Nineteenth Century when civilization moved westward in response to prospecting for gold (Figure 1.8). Even after achieving statehood, Arizona's population did not begin to significantly increase until the latter half of the Twentieth Century. During the 1970's, Arizona's population nearly doubled by immigrants from other states. The increase in population was due largely to the attraction to the climate and by employment opportunities. Today, the population registers at 3,936,000. Arizona is the sixth largest state in the United States, occupying 2,950,243 square kilometers.

General Physical Geography of Arizona

Arizona borders the states of California, Nevada, Colorado, Utah, New Mexico, and the country of Mexico. Topographically, Arizona is divided into three macroregions (Figure 1.9). The first of these is the high plateaus of the north, also known as the Plateau Uplands Province. The second macroregion is more of a transitional area known as the Central Highlands Province. This macroregion serves as a transitional area between the uplands of the Plateau Uplands Province and the lowlands of the Basin and Range Province. This last macroregion, the Basin and Range Province encompasses the desert plains and mountains of the southwestern section of the state. The basic topographic configuration of these macroregions are directly related to the generalized

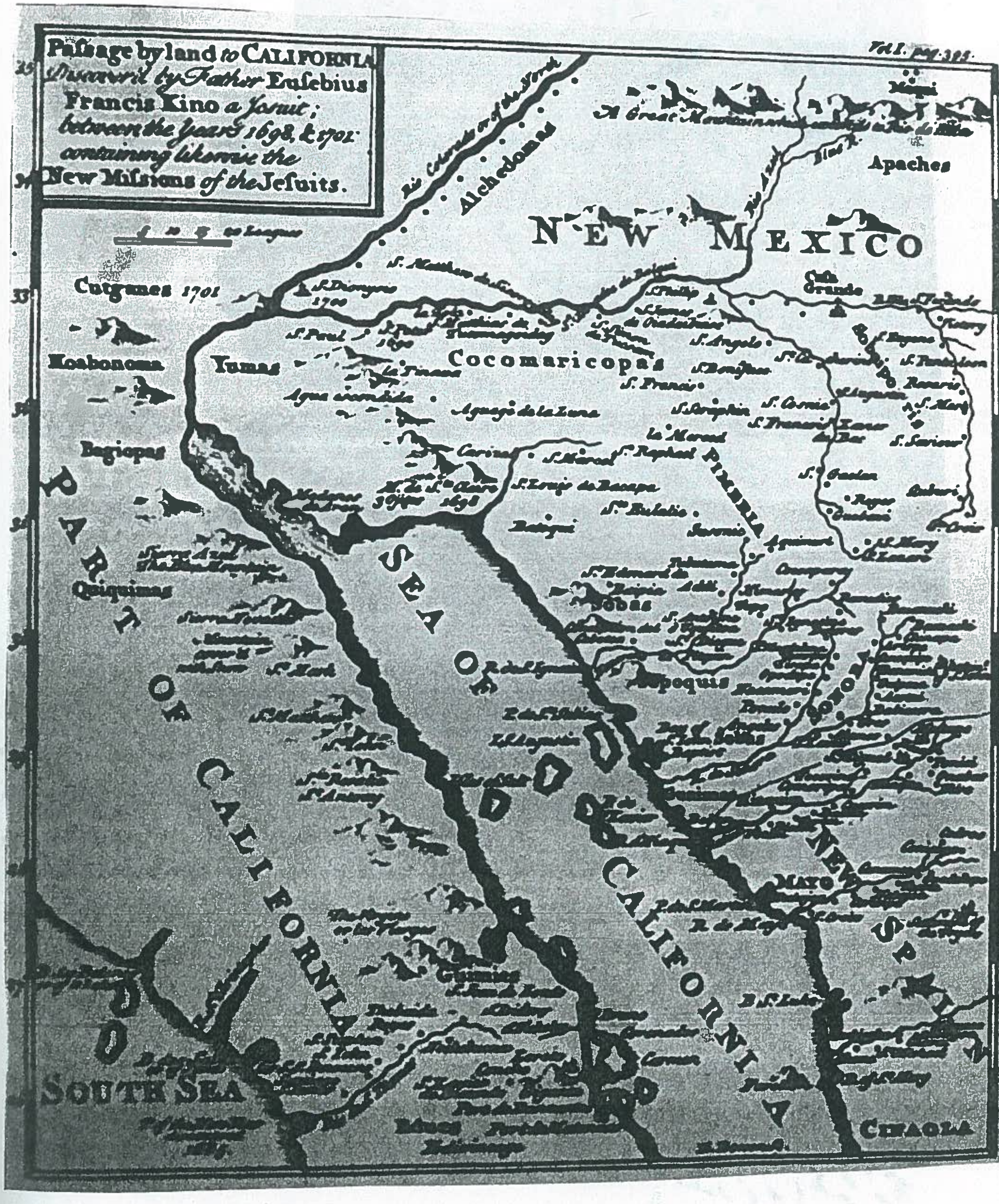


Figure 1.8: Passage by Land to California

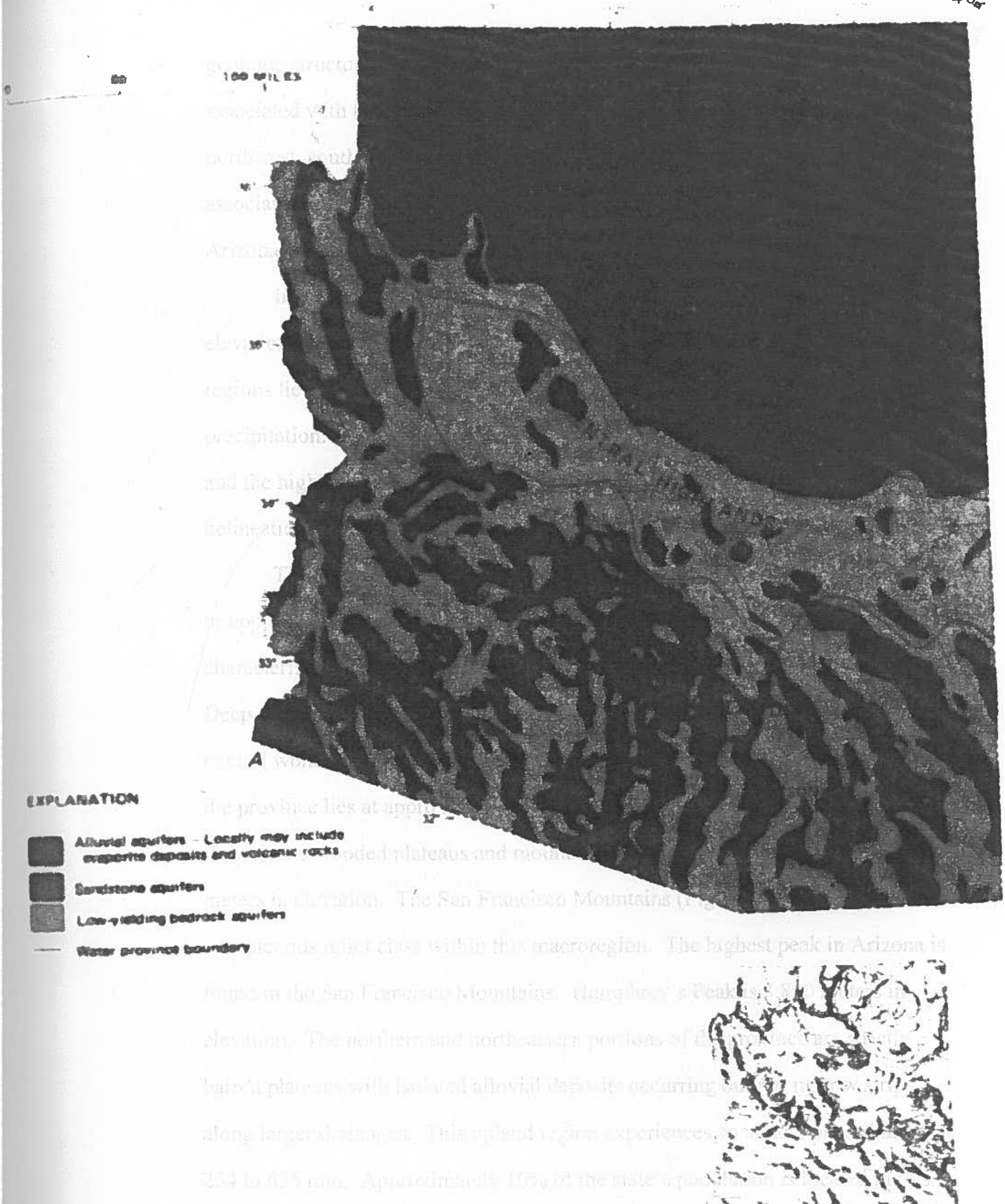


Figure 1.9: Three Macroregions of Arizona

geologic structure. The southwestern and central plains and mountains are associated with the Basin and Range Province that extends from Idaho in the northwest, south to Mexico, and east to Texas. The high plateaus of the north are associated with the Colorado Plateau that centers on the "four corners" area of Arizona, Utah, Colorado, and New Mexico.

In general, the desert regions of Arizona lie below 1,000 meters in elevation and receive less than 230 mm of precipitation. Generally, Steppe regions lie between 500 and 2,500 meters and receive up to 460 mm of annual precipitation. The foothill zones lie primarily between 1,500 and 2,000 meters, and the highland regions are generally delineated above 2,000 meters. These delineations are arbitrary in that sharp borders cannot be derived in every instance.

The Plateau Uplands Province occupies 40% of the land area of the state, or approximately 118,000 square kilometers. The Plateau macroregion is characterized by flat-topped mesas and buttes of very high relief (Figure 1.10). Deep canyon formations, inclusive of the Grand Canyon, one of the world's seven natural wonders, are also characteristic of this northern province. The majority of the province lies at approximately 1,524 meters, however, north of the Grand Canyon are wooded plateaus and mountain peaks which rise to more than 2,438 meters in elevation. The San Francisco Mountains (Figure 1.11) are a conspicuous relief class within this macroregion. The highest peak in Arizona is found in the San Francisco Mountains. Humphrey's Peak is 3,850 meters in elevation. The northern and northeastern portions of the province are strictly barren plateaus with isolated alluvial deposits occurring only as narrow strips along larger drainages. This upland region experiences an annual precipitation of 254 to 635 mm. Approximately 10% of the state's population is located in this region. The rugged physiographic features have prevented urbanized

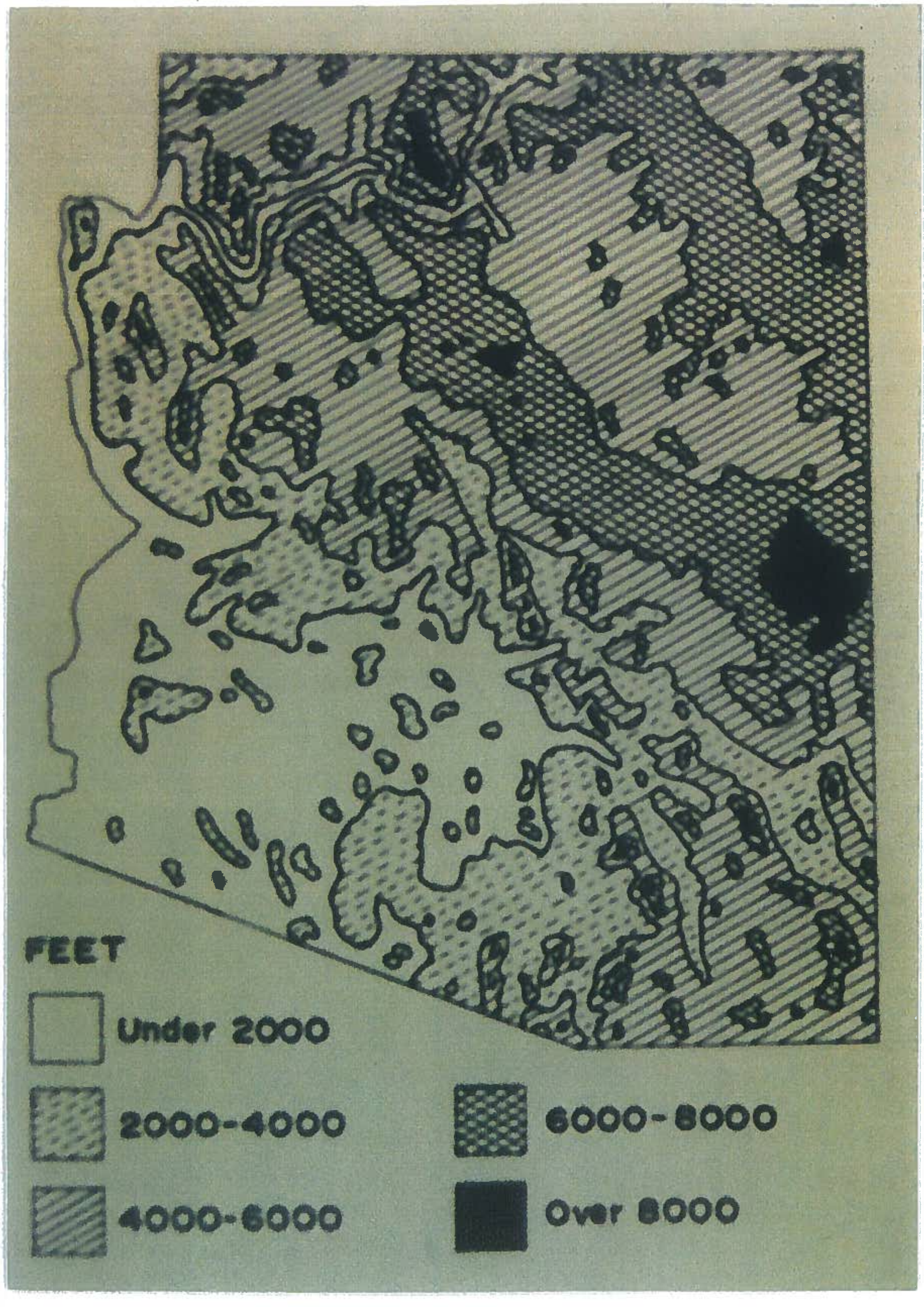


Figure 1.10: Generalized Relief of Arizona

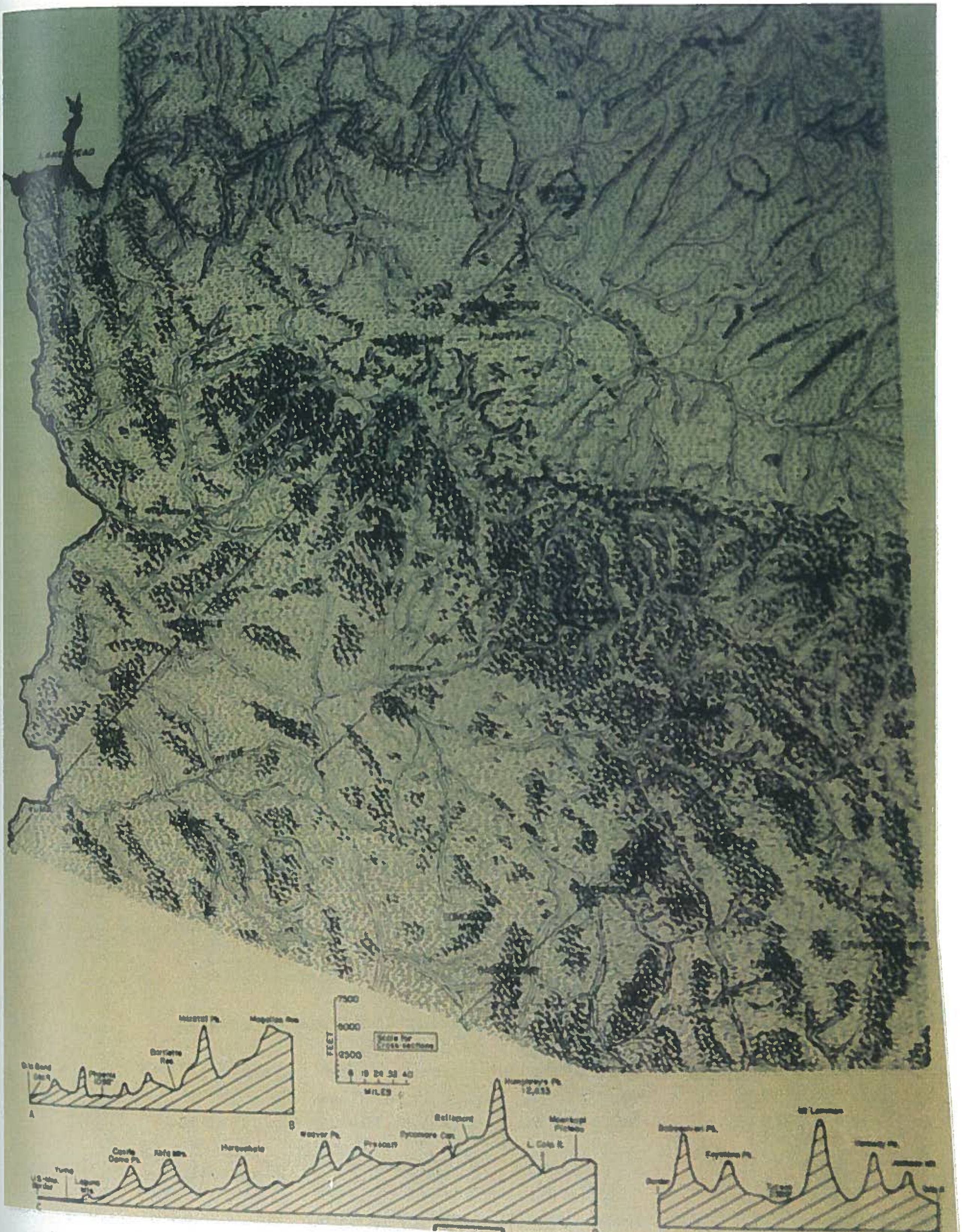


Figure1.11: Physiographic Diagram of Arizona

development.

The Central Highlands Province forms a topographic high extending diagonally northwest to southeast across the central portion of Arizona (Figure 1.9), serving as a transitional zone which separates the Uplands from the Lowlands Provinces. The macroregion is characterized by a mountainous area fractured by relatively small, shallow valleys which are not interconnected. The mountains of this area are of an open high or open low relief type or are low mountains. The macroregion comprises slightly over 44,000 square kilometers, or 15% of the state's land area. Almost 10% of the state's population resides in this area. The Central Highlands Province characteristically receives the greatest amount of annual precipitation in the state, registering at approximately 380 to 880 mm.

Physical Geography of the Basin and Range Province of Arizona

Extremely arid conditions exist in a number of areas of the southwestern United States. Desert and steppe conditions prevail in Baja, California, Sonora (Mexico), southeastern California, Nevada, across the Continental Divide into New Mexico and Chihuahua (Mexico), and in Arizona. This wide region is referred to as the Sonoran Desert (Figure 1.12). This region is not always clearly defined. A number of criteria could be used which would either limit the area of the Sonoran Desert to the extremely arid core at the head of the Gulf of California, or extend its boundaries to include the marginal deserts and transitional semiarid grasslands.

The margin of the Sonoran Desert does in fact shift both seasonally and annually. During a series of drought years, the Sonoran desert expands. In wet

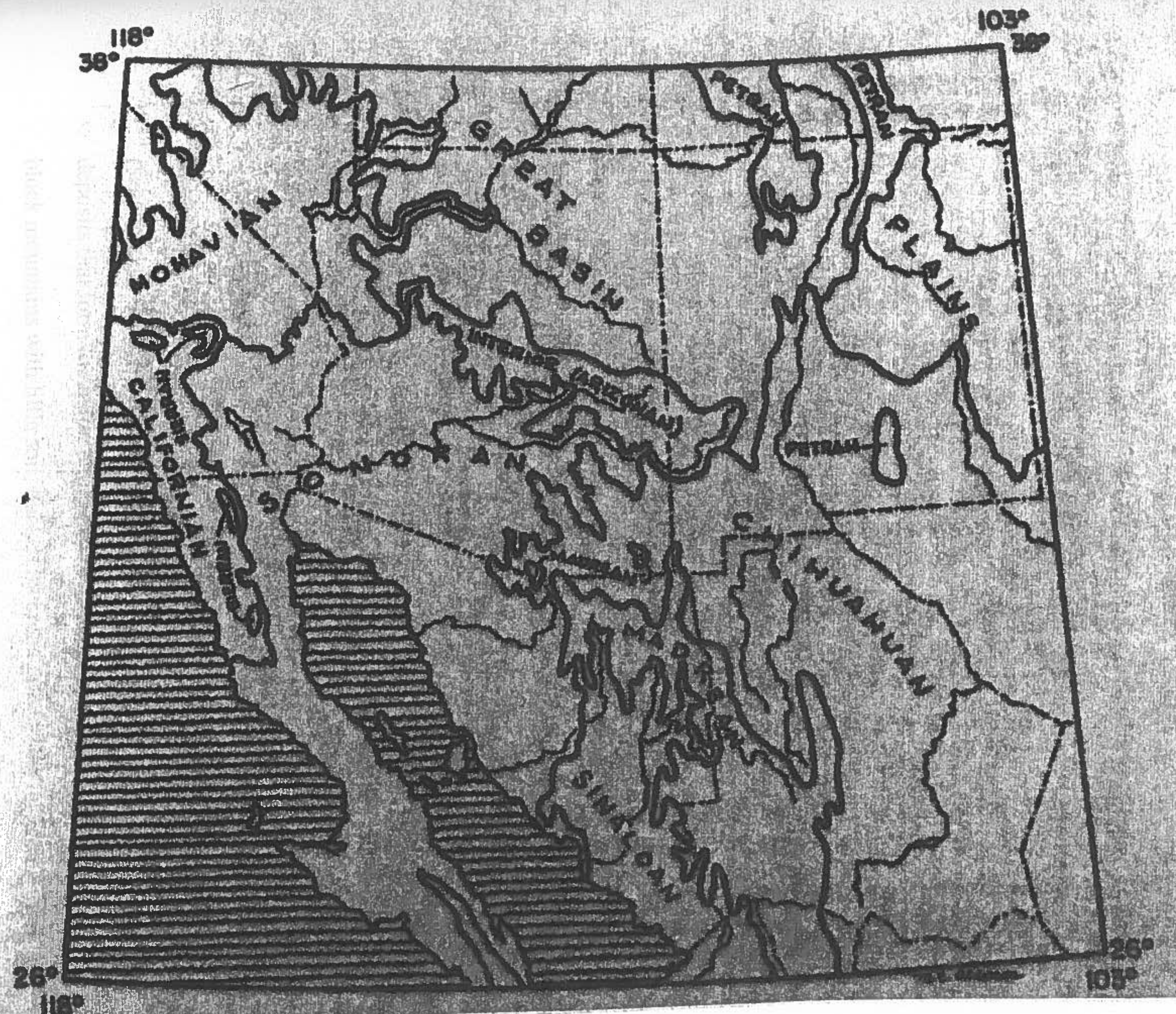


Figure 1.12: Biogeographic Provinces of the Southwest

years, the Desert significantly contracts leaving many small desert enclaves surrounded by newly created steppe lands. The desert is therefore basically a climatic province which receives less than 305 mm of precipitation annually. Characteristic of the Sonoran Desert are ubiquitous, isolated block-faulted mountains and intervening outwash plains. From northwest to southeast, the rugged, disconnected mountains line the desert in such a way that the mountains are always in the background of the arid plain. This alteration of plain and mountain has been defined physiographically as the Basin and Range Province (Figure 1.9). It is specifically characterized by roughly parallel and discontinuous mountain ranges separated by continuous basins. The width of the basins are generally greater than the intervening isolated mountains.

Since the "boundaries" of the Sonoran Desert lie outside of Arizona, as well as outside of the regions in Arizona that are the topic of discussion and analysis (specifically, the central northern Basin and Range Province), discussion of the Sonoran Desert will be limited to this region of the Basin and Range Province, in which the Phoenix metropolitan area is found.

The characteristic physiographic feature of the Basin and Range (Lowlands) Province are isolated mountain ranges and broad alluvial valleys. The extremely dry desert lowlands receive an annual precipitation of 102 to 305 mm, and the mountain ranges receive anywhere from 510 to 762 annually. the annual average precipitation for the region on the whole is 420 mm or less. The valleys (separated by the linear trending mountain ranges) contain unconsolidated deposits that form the major aquifers of the state. The ranges are rocky fault-block mountains with little soil, flanked by broad gravel fans that slope from the foot of the mountains to the basins.

The basic geologic features of the Basin and Range Province were formed by several stages of erosions and depositions of sediment. Consolidated sediment, characterized as "older alluvium" composes the largest volume of valley fill. A slightly less consolidated alluvium consisting of gravel, sand, and silt from the overlying deposits is characterized as "younger" alluvium. Loosely consolidated sediment representing the most recent alluvial deposition occupies the present stream courses which cut into the valley floors. The macroregion occupies 132,763 square kilometers, or 45% of Arizona's land area. More than 80% of the state's population is found in this physiographic province (Figure 1.13). The historically dependable and suitable groundwater resources in this region have significantly influenced the population distribution within the area. Abundant groundwater supplies were present in extensive alluvium deposits which extended to a combined depth of a few thousand meters. Today, groundwater overdraft of these supplies have become the main concern in providing for the water needs of more than 2 million residents.

The General Climate of Arizona

The climate classification scheme used in Arizona is the Köppen system. Based on this system, six climatic types are delineated in Arizona (Figure 1.14). An arid (dry) subtropical (warm) climate prevails throughout the southwestern third (northern Sonoran Desert) of Arizona and the low valleys tributary to this area. Intermediate elevations in the southwestern half of the state are semiarid and subtropical, as are the lower portions of the Plateau Uplands Province.

However, the majority of the Plateau is isolated from moisture surfaces and exposed to invasions of cold air from the north in the winter, and is characterized by semiarid "continental" weather schemes rather than the

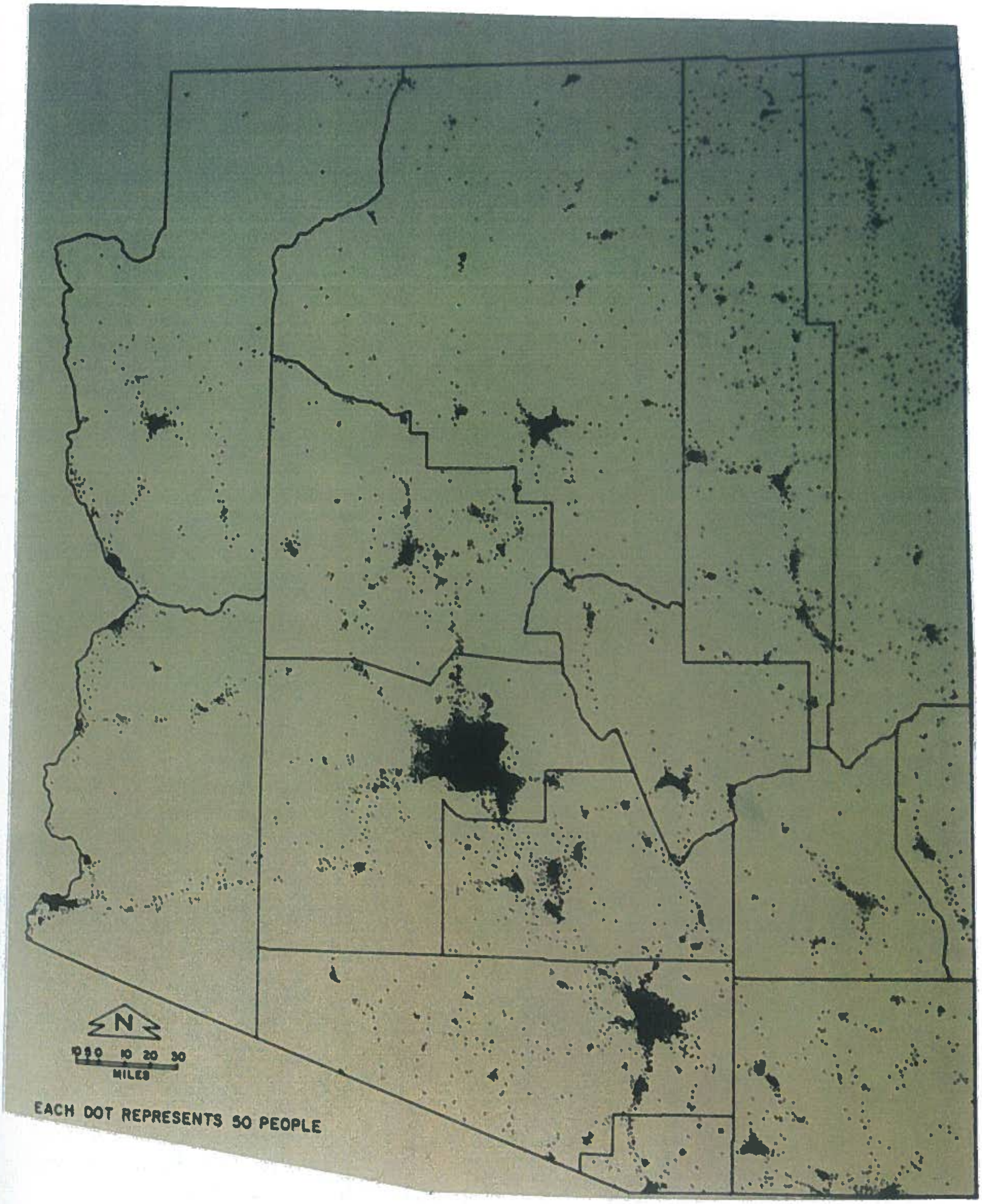


Figure 1.13: Population Distribution

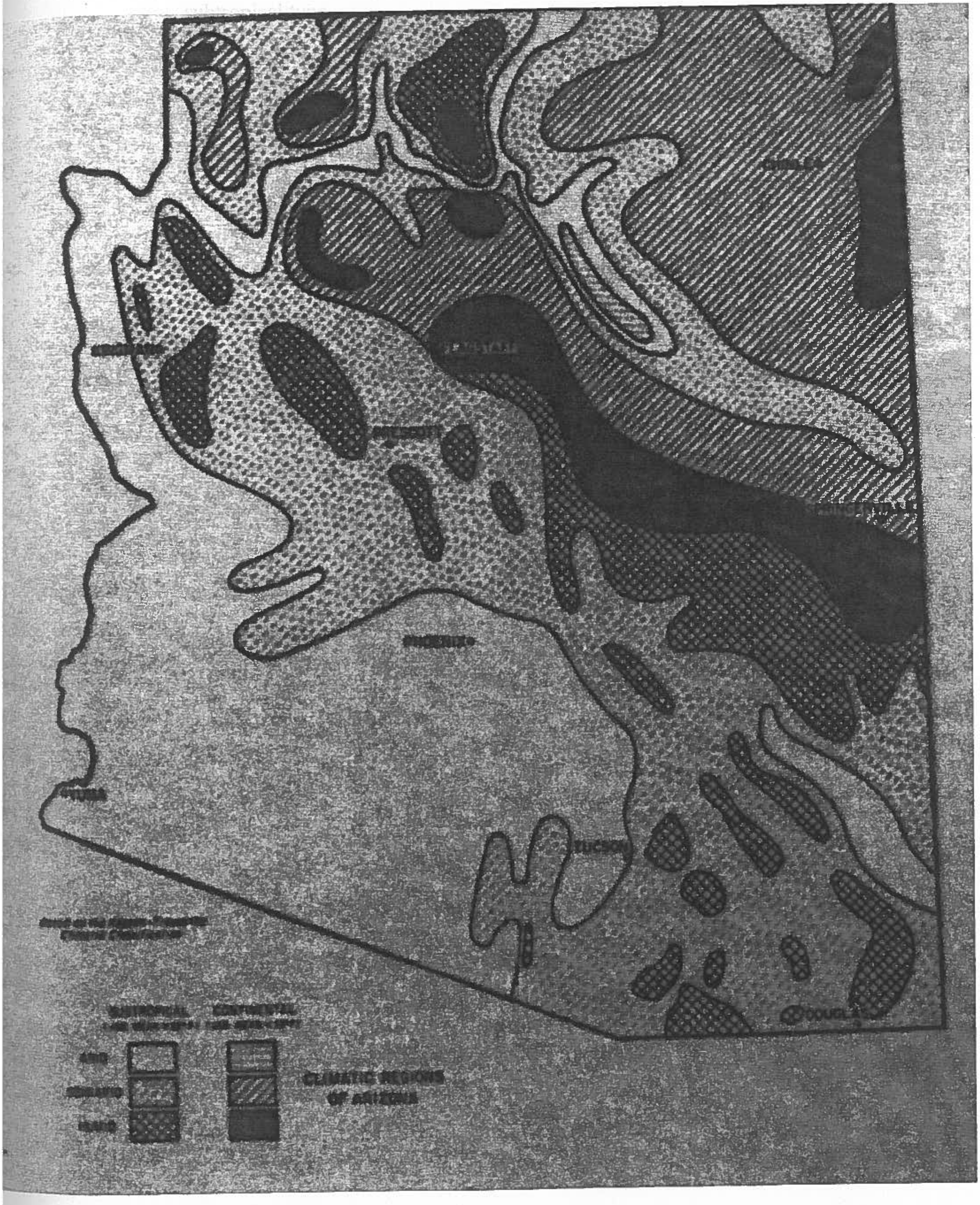


Figure 1.14: Koppen Climate Regions

subtropical type.

High elevations in the mountains receive a relative abundance of precipitation and experience sufficiently low temperatures, thereby classifying the region as humid. The highest and/or most northeasterly of these mountains are cold enough to be considered continental. The only significant area of arid continental climate or cold desert is marginal to this category and situated in the Little Colorado River Valley on the Colorado Plateau.

If one were to map general regions of the state via their climatic characteristics, 10 regions would appear. Each of these are categorized based on relative relief as a main delineating factor. This is in comparison to the Köppen system, which strictly uses a precipitation and temperature combination regime to distinguish climatic zones. The 10 regions could be considered micro climatic regions of the three major physiographic provinces. The Colorado River Valley is a zone, located in the Uplands Plateau Province, that is relatively dry and extremely hot in the summer but the principal weather element that sets it aside from neighboring zones is wind. The Valley of the Colorado carries water to the gulf of California and acts to channel air movements up and down stream. Generally, downstream flows of air are greatest in winter and at night and upstream flows greatest in the summer and daylight hours.

Northwest Arizona, also located in the Uplands Plateau Province, is characterized by varied topography and its boundaries are rather artificial. In elevation, it ranges from approximately 300 meters to over 2,400 meters. In this region, winters are severe and abundant snow falls on the higher slopes when cyclonic storms cross the region. Summer temperatures along the southern and western margins are high but the higher elevations are appreciably cooler. According to the Köppen system, this area could be classified as very varied inclusive of arid subtropical and arid continental, semiarid subtropical and semiarid continental, humid subtropical and humid continental climatic orientations (Figure 1.14).

The Grand Canyon exhibits the greatest local relief of anywhere in the state, and therefore large temperature variations occur within it. Physiographically, the Grand Canyon belongs to the Uplands Plateau Province. The bottom of the Grand Canyon is much hotter in the summer than are places in the higher plateau country in the north. Winters are cold everywhere in this climatic region.

The Central Basins and the Mogollon Rim are two transitional climatic regions belonging to the Central Highlands Province. The Central Basins would more accurately be named the Central Ridges and Basins due to the fact that the area consists of rough and undulating terrain that marks the margins of the Uplands Plateau Province. As a climatic zone, it represents a transitional zone between the southwest deserts and the higher country lying at lower elevations. Precipitation is almost equally distributed between the winter and the summer. The Mogollon Rim constitutes the "Rim Country" of the edge of the Uplands Plateau Province. The edge of the Rim Country is marked by higher elevations than the land on either side of the rim. Consequently, the area is cooler, cloudier and wetter in every season than are most other parts of the state.

The coldest and snowiest portion of Arizona is the White Mountains found in the southeastern portion of the Uplands Plateau Province. Over 10,160 mm of snow have been recorded in this region. According to the Köppen system, the White Mountains are a humid continental climatic region.

The Little Colorado River Valley contains the main stream of northeastern Arizona, the Little Colorado. This river, which is dry throughout most of the year, lies in a structural basin leading to the Grand Canyon of the Colorado. The climate of this valley is distinctly drier and clearer than the sections lying to the south and to the west. This zone is also hotter in the summer and may experience cold ice fogs in the winter when a cold air pool forms as a result of stagnant atmospheric conditions. In some places, it may also be very windy due to the down slope flow of the prevailing southwest winds and the fact that there are few trees to impede the movement of air.

The Northeast Plateau consists of a region of stark landscapes which are the result of differential erosion produced by wind and rain and the pressure placed on the land by man. Primarily, the area has been overgrazed, thereby leaving it susceptible to the forces of nature. Droughts generally occur more frequently here than anywhere else in the state, presumably because the winter rains and snows that are depended upon to rebuild the range are less dependable than are the summer rains that feed the ranges in, for example, southeastern Arizona. Since the majority of this land is located on an Indian Reservation, accurate weather data are not usually kept. Additionally, policies governing Indian land use are determined by the tribal councils. Therefore, Reservation lands cannot be realistically discussed in the content of this document due to the futility of formulating proposals for new environmental management techniques of these areas. Generally, the area is arid, cold in the winter, hot in the summer and windy.

Southeast Arizona is a region of mountains and valleys noted for its summer thunderstorms. Winters are cool to cold at higher elevations. This climatic microregion belongs to the eastern portion of the Basin and Range Province. According to the Köppen system, the majority of this area would be classified as semiarid subtropical, with scattered patches of arid subtropical and humid subtropical regions.

The Climate of the Northern Basin and Range Province

In general, this climatic region represents the type of climate that most people associate with Arizona. It is classified as an arid subtropical region, thereby marked by extreme heat and low rainfall. Since mountain ranges encircle the low-lying regions of much of the desert, the moisture that might otherwise be available to the dry lowland plains is stolen. A number of factors contribute to the aridity of this region: 1) there is a relative weakness of any internal pressure system; 2) it is a distance from the polar and tropical zones of convergence; 3) the incoming air is heated; 4) the intermontane location; and 5) there is intense local sunshine and evaporation.

Precipitation registers at less than 400 mm annually. The limited rainfall is divided into two well-defined rainy seasons. Winter rainfall usually begins in November and continues, with many interruptions, into March. These rains are of the Mediterranean type. They occur during the period when the Pacific subtropical high has moved farthest south, allowing passage of low pressure areas across the southern margin of the continental land mass. Summer rainfall, the bulk of the which occurs in July, August and September, has a contrasting tropical origin. The North Atlantic subtropical anticyclone strengthens in June and penetrates westward. A westward circulation of air around the southern margin of the high brings moist tropical air into the region from the Gulf of Mexico in late June. It replaces a westerly flow from the stable eastern end of the North Pacific anticyclone which dominates the desert during the early part of the month. The abrupt beginning of thunderstorm activity marks the arrival of the Gulf tropical air. The Pacific anticyclone is forced north by the humid southeasterly current from the Gulf of Mexico.

The summer rains last for several days followed by several days of dry weather. They are scattered, with each storm effecting no more than a few square miles. Individual showers are separated from each other by large areas of dry ground. The thunderstorms are of a short duration but are very intense, particularly at the beginning of a storm. This "cloudburst" which may last only a few minutes gives rise to flash floods, damage to crops, roads, and other structures. The Phoenix area of the Basin and Range Province receives approximately 200 mm of rain each year (Figure 1.15).

Unlike precipitation, temperature in the central northern Basin and Range Province has shown to be fairly consistent from year to year. However, the temperature cycle is not as simple and predictable as it once was. Phoenix and its environs are becoming warmer each year for longer periods of time and warmer during times it has not historically been warm. Summer temperatures of June, July, August and September have traditionally registered at over 38°C, with a 50% probability of the temperature being over 42°C. Summer temperatures have been breaking records for the past seven years, as days over 46°C are now much more prevalent. Additionally, the high temperatures are beginning earlier than June and remaining far later than September. It is hypothesized that part of the reason for this is that increasing populations in the north central area of this province are bringing with them increasing vehicular emissions which are acting to retain some of the heat.

Winter temperatures are cool to mild, however some areas occasionally report O°C weather during the three to four month winter period. Throughout the region, elevation is a significant control on the annual number of frost-free days.

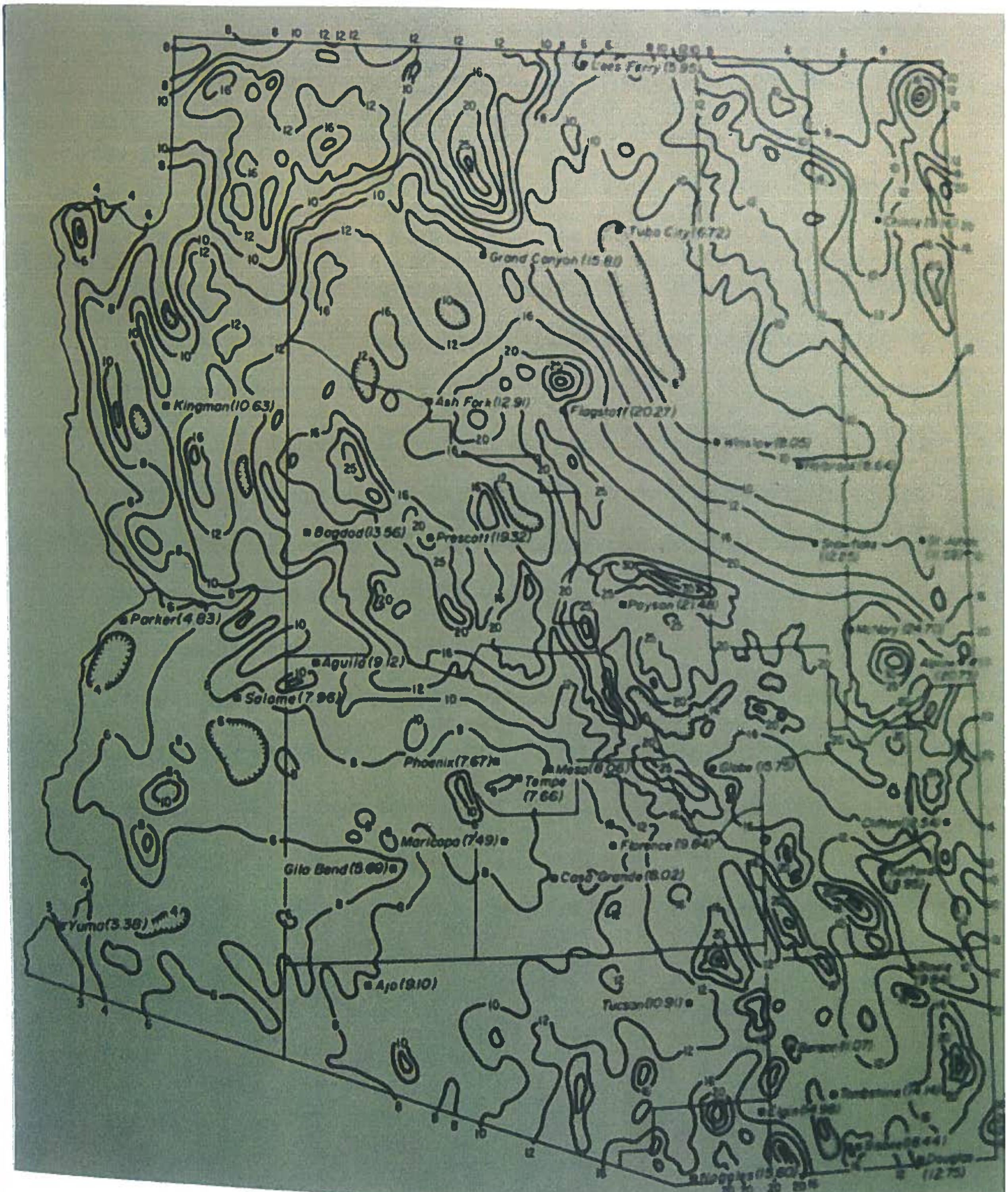


Figure 1.15: Annual Rainfall in Arizona

The length of the growing season is reduced by approximately 30 days for every 305 meter increase in elevation. This, in conjunction with the irrigation system of the region, allows for a growing season sufficiently long to plant and harvest two crops. Diurnal temperature ranges are great during any season, being slightly broader in the early summer than in the winter. Clear skies contribute to the daily temperature fluctuations.

The surface winds of the north central Basin and Range Province are generally controlled by the interaction of the North Pacific High and the "Sonoran" Low. The Pacific High pressure system shifts with the seasons from about 40° North to 24° North latitude, whereas the latter system is relatively a permanent phenomenon. The winds of the north central Basin and Range are out of the south and southeast. With the progression of the summer season, convection currents bring about stronger local controls on air circulation. The overall regional pattern is blurred by the rising and subsiding currents which form cells over the enclosed basin. After a sunrise, a wind begins to blow outward in all directions from the center of the desert.

The peripheral mountains engender conditions resulting in the concentration of convection currents over their flanks and summits. These are often marked by banner clouds. Shortly after sunset the opposite condition prevails, with a desiccating hot wind blowing down toward the Basin's center. This adiabatically heated air continues throughout the early evening and is replaced by a cool wind from the same direction before dawn.

The Soils of Arizona

The five factors that have been considered in the formation of the various soils in Arizona are parent material, topography, climate, biotic interactions, and time. The soil types of Arizona can be divided into general types based on their formation by the above-mentioned factors. The soils of the steep mountainous areas is the first of these types. The steepness of the slopes allows for rapid removal of friable soil material by water and gravity. Climate and biotic interactions, therefore do not play as large of a role in the soil-forming processes on this type of soil as they do on others in comparison. The texture and chemical composition closely resembles that of the parent material. The influences of climate and vegetation can be observed in the color and organic matter of the top layer. Being shallow over rock material, these soils store little water for plant use.

The deep soils of the river flood plains are subjected to periodic flooding due to their proximity to waterways. Physical and chemical characteristics of these soils are largely determined by the composition of the sediments deposited by the flooding waters at given times. Texture is primarily determined by the speed of the water. Since these soils are formed from sediments washed from higher elevations, their organic matter content and color are often not indicative of the climate in the area. For this reason, soils in Arizona are primarily classified according to the soil temperature at a depth of 152 centimeters. A soil is classified at thermic if the temperature is over 15°C, mesic if over 8.3°C, and frigid if the temperature is less than 8.3°C.

In Arizona, the majority of the area above 1,800 to 2,100 meters in elevation is forested. The types of soils formed in these areas can be separated into 2 major groups: 1) those that do not have light-colored, leached upper horizons, and 2) those that have light-colored leached upper horizons. The first group of soils developed in basalt and cinder parent material. The second group of soils developed in limestone, sandstone, and Tertiary and Quaternary parent gravel materials.

Soils of the North Basin and Range Province

Throughout the region, extremely arid conditions, heat and wind working upon the isolated block faulted mountains and the slopes of the larger ranges have repeatedly produced similar soils. This repetitive occurrence of like soils in similar situations over a wide expanse of desert is due to the textural differences of soils which develop in a vertical sequence from mountaintop to floodplain. Climate indirectly effects desert soil through the limitations placed on plants. An incomplete plant cover leaves the soil exposed and results in high rates of erosion and deposition both by wind and water. The restricted plant growth results in the low humus content of the soil. The soils are generally shallow with a low humus content. Most of soils of this region lack a well-defined profile.

In areas where the slopes are not so steep as to cause the rapid removal of the surface soil, the soil-forming processes have time to form characteristic soil morphology. Clay accumulates in the subsoil of the developed soils of the thermic and mesic regions. Clay mineral studies have shown that illite is the predominant clay mineral in the solum. Carbonate has also accumulated within 100 cm of the surface of most of the soils. The presence of carbonate causes the well-known "caliche" layer to form. Montmorillonite is common in the calcareous carbonate-enriched subsoils. Organic matter content and the carbon:nitrogen ratio of the surface horizon is low. The low organic matter content is hypothetically due to the sparse vegetation and high temperatures. The low carbon:nitrogen may be due to the presence of nitrifying bacteria in the soil.

Cracking, clayey soils have developed in this mesic region of the state on nearly level basalt flows. They possess a high clay content and therefore churn each year due to seasonal wetting and drying. Lastly, the saline-alkali soils are located in the central portion of the state and possess high concentrations of sodium and soluble salts. These soils have resulted from the concentration of run-off water into an enclosed drainage basin where the water is then lost via evaporation.

The Vegetation of Arizona

The natural vegetation of Arizona can most efficiently be described by delineating the naturally-occurring biomes that are created due to topography, soil types, and climate. As usual, the delineating factor of any given ecosystem is the vegetation of that area. The regions of southeastern Arizona, and the northern half of the state can be differentiated into seven different ecosystems (Figure 1.16), based on the type of flora found in that region.

The San Francisco Mountains of the Uplands Plateau macroregion are a type of Tundra characterized by low, treeless vegetation that exists above the timberline. The elevation of the San Francisco Mountains is 3,862 meters and represents the only well-developed alpine tundra in Arizona. There are 88 species and subspecies of vascular plants which are distributed between two of the three habitats of the region: the alpine meadow, which contains the richest assortment of vascular plants; the boulder field (represented by large areas of layered and overlapping rocks in a matrix of finer rock debris that provide some shade and

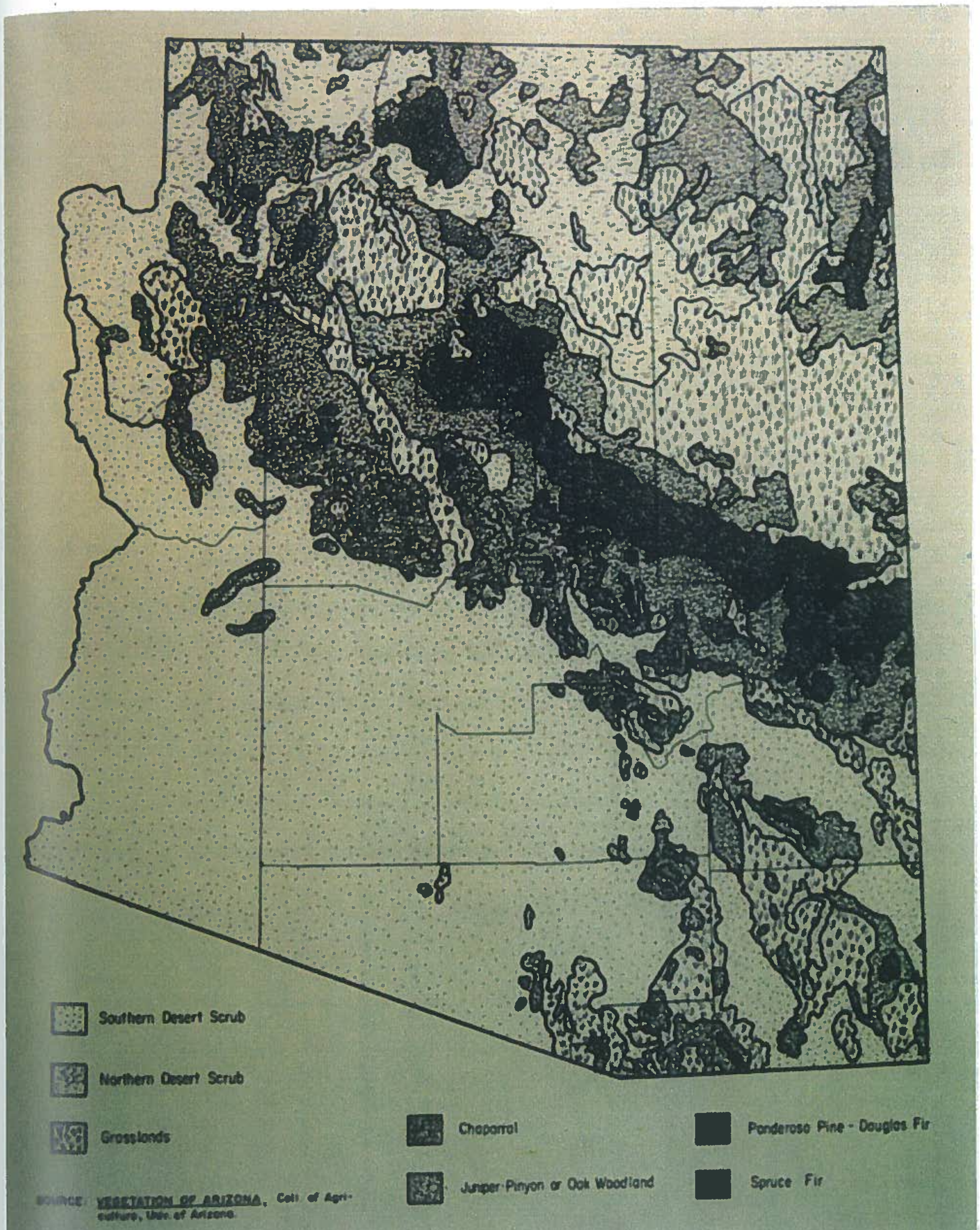


Figure 1.16: Vegetation in Arizona

protection from drying winds) contains a limited number of vascular plants; and the fell field, which is the most severe environment, there is little soil and limited protection from the elements in this biotic microregion. Lichens and mosses abound in this habitat. However, the environment is too severe for vascular plants. Stands of bristlecone pine, corkbark fir, and Engelmann spruce are the dominant feature of the landscape. The strawberry and dandelion are prominent in (and confined to) the boulder field.

In the eastern and southeastern portion of the state, there is the Madrean Montane conifer forest, which is qualified as a cold temperate forest and woodland. Included here are both pine and fir stands, which are representative of a transition zone. The Ponderosa Pine grows in natural stands, occupying 3.4 million hectares between the states of Arizona and New Mexico. There are also subclimax stands of aspen and birch.

Within northern Arizona and transversing northwest to southeast across the state there is a cold temperate forest and woodland biotic community that is represented by juniper and pinyon conifer stands. This woodland has one of the most extensive vegetative types in the southwest. Important plant associates to the Juniper-Pinyon stands are the oak and several shrubs such as mormon tea. Cactus that is present in these regions are the hedgehog and prickly-pear. This region is delineated at 1,500 to 2,300 meters.

The interior chaparral of Arizona can be qualified as a warm-temperate scrubland. Chaparral is an important vegetation type in Arizona, as it cover 1.4 million hectares (Figure 1.17). The interior chaparral discontinuously occupies mid-elevation (1,050 to 2,000 meters) of foothill, mountain slope, and canyon habitats, all of which experience a precipitation of less than 300 mm. The chaparral is generally found in southeastern Arizona and in central Arizona, just

Figure 1.17: Interior Chaparall of Arizona

bordering the Central Highlands macroregion and the Basin and Range macroregion. Shrub live oak is the most widespread and dominant plant type of this area. Accompanying the shrub live oak are the associative plants of catclaw acacia and jojoba.

There are two types of grasslands in Arizona, the alpine and subalpine grasslands of the White Mountains and Kaibab Plateau, and the plains and Great Basin Grasslands of southeastern and northern Arizona (respectively). The alpine and subalpine grasslands occupy valleys, slopes, and ridges on flat terrain adjacent to subalpine forests. Perennial bunch grasses, clover, larkspur, and dandelions are all typical examples of this grass and herb dominated region.

The grasslands of the plains and Great Basin are situated on open areas and are therefore greatly exposed to solar radiation and winds. The plains grasslands of southeastern Arizona are situated above 1,200 meters in elevation where precipitation averages between 300 and 460 mm annually. The majority of the plains grasslands consist of mixed or short-grass communities. The principal grass constituents are perennial sod-forming species of gramas. Buffalo grass and Indian rice grass are also prominent. Shrubs such as the cholla, soapweed and sumac are dominant. The grasslands of the Great Basin, also known as intermountain grasslands, are found in northern Arizona. These grasslands occur in slightly higher elevations and relative precipitation levels when compared with the grasslands of the plains. Sagebrush is the predominant vegetative type of this region. The principal grasses are alkalai sacaton, galleta, blue grama, and Indian rice grass.

The wetlands of Arizona have been decreasing for over the past 10 years. Conditions for this ecosystem are provided by flood plains (riparian zones) of drainage ways and poorly drained lands. Increasing aridity in Arizona has resulted in the permanent loss of many rivers, and ephemeral and perennial streams. The still-existing riparian habitats of Arizona include the Colorado River and Mormon Lake. Vegetation of these regions have also disappeared due to the progressive loss of their habitat. Dominant flora include the Gooding willow, the Freemont cottonwood, the narrowleaf cottonwood, and maple. Saltcedar is an introduced plant that now predominates many of the riparian habitats, but has assisted in the progressive loss of natural vegetation due to its tenaciousness. Saltcedar also has higher water requirements than did its natural predecessors.

Vegetation of the North Basin and Range Province

This macroregion could be qualified as having a southern desert scrub type vegetation. Giant cacti and small xerophytic trees dominate the landscape. The flora that have been able to perpetuate themselves in this environment are especially adapted to gather and conserve moisture, to withstand great heat and wide diurnal temperature variation, and are able to overcome the danger of windblown particles and shifting sand. The majority of the area is low-elevation desert composed of low-gradient or nearly level plains of gravelly outwash or sand. The region of interest in the northern Basin and Range Province is actually composed of two vegetational subregions of the desert scrub region: the Lower Colorado Valley Desert and the Arizona Upland Desert (Figure 1.18).

Upon the extensive intermontane plains, the vegetation is usually limited to open stands of creosote and bur sage (Figure 1.19). This characteristic represents the Lower Colorado Valley Desert. Pure stands of creosote form the most distinctive aspect of this region. These plants predominate due to their low moisture requirements (with survival rates in areas with less than 130 mm of

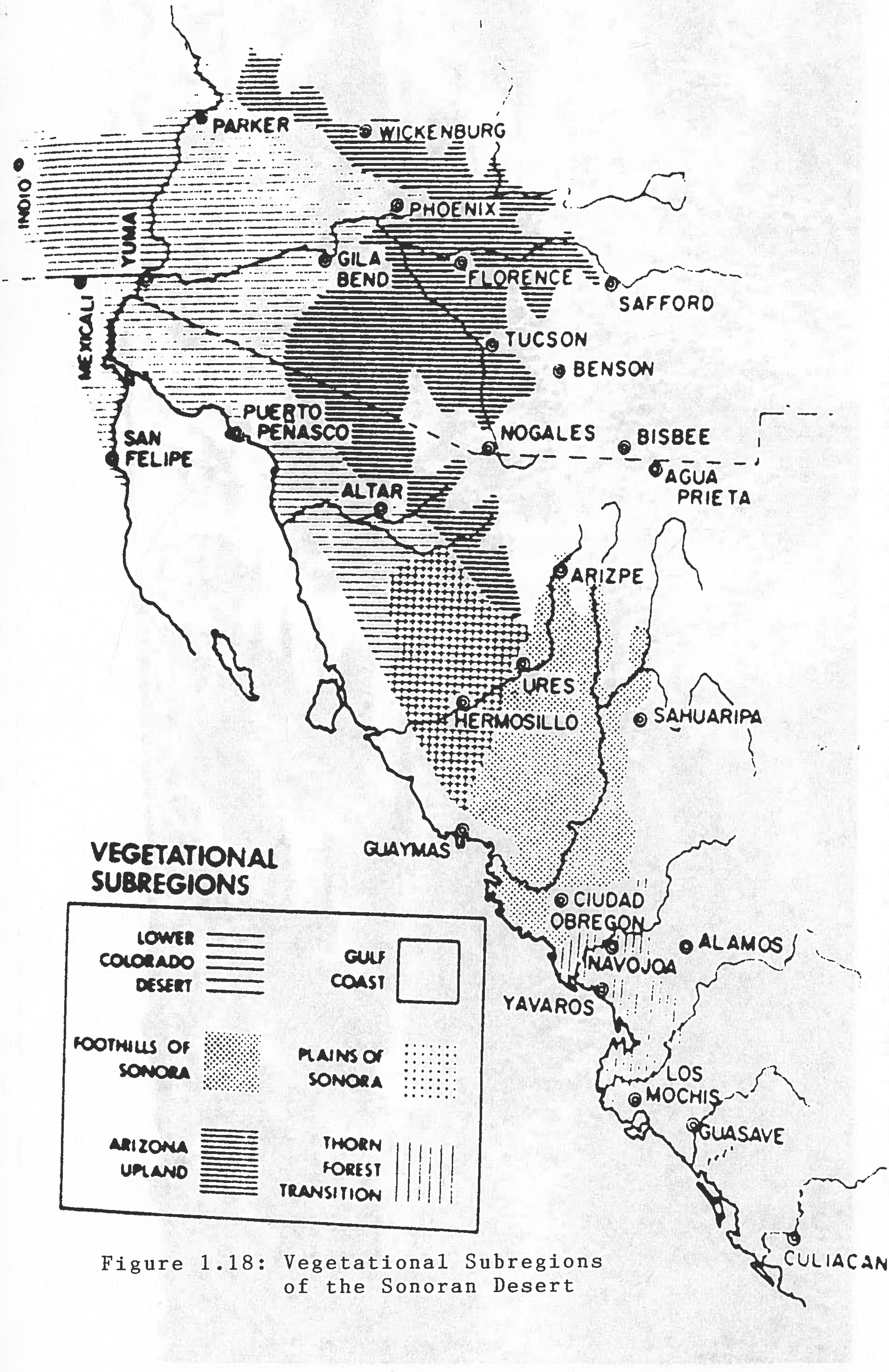


Figure 1.18: Vegetational Subregions of the Sonoran Desert

Figure 1.19: Desert Scrub of the Lower Colorado River VAlley

rainfall) and their drought resistance. The trees which are commonly found along the larger stream ways are the blue palo verde, the mesquite, the ironwood and the smoke tree. The latter of which is almost entirely confined to the bottoms of sandy washes where water is most easily attained. Areas of greater subterranean moisture are indicated by the observable change in vegetation. The stands of plants become thicker, the statue greater and the number of trees and cacti increases.

Such is the case in the Arizona Upland Desert (Figure 1.20), which lies just to the east of Phoenix. In contrast to the Lower Colorado Desert to the west, this region can most easily be characterized by increased rainfall and a more rugged relief, thereby serving to support the distinctive larger forms of vegetation. In this area, palo verde and the giant saguaro cactus predominate the landscape. The stands of creosote and bur sage are just as prevalent, but not as noticeable. Teddy bear cholla, jumping cholla, ocotillo, and brittlebrush are important associative species in the palo verde-saguaro community. Well over half of the total surface area is composed of mountains and hills. The coarser soils which have developed on these land forms best support the distinctive larger vegetative forms. However, the poorly drained clay and clay-loam soils and the salt-impregnated soils of the desert result in the presence of vegetation more closely resembling the type found in the Lower Colorado Valley Desert. Greater variations in land forms, soil and drainage within the Arizona Upland results in a varied plant cover which is unequaled in the Lower Colorado Desert where there is a dearth of upland soil types.

Of at least equal importance to plant growth is the increased rainfall which is, in part, due to the general higher elevations and more massive mountain ranges that intercept the major rainbearing air masses which pass unimpeded over the

Figure 1.20: Vegetation of the Arizona Upland Desert

low-lying plains, deltas, and miniature mountains to the west and southwest. Desert vegetation can be expected to be found up to approximately 9,100 meters in elevation on the mountain ranges to the north and east which rise above desert conditions. Three hundred to three hundred and eighty mm of annual rainfall generally coincides with this elevation and gives an approximate boundary between the true desert and semiarid vegetation.

Hydrological Conditions in Arizona

The Native American irrigation network, built by the Hohokam Indians in prehistoric times with only sticks and stones, stretches from the Salt River to the Mesa, as well as across much of the west valley of Phoenix. The Hohokam's were Arizona's first farmers, a feat accomplished by diverting the Salt River to meet their irrigation needs for the growth of corn, beans, and squash. These canals were as large as 6.08 meters wide, up to 1.52 meters deep, and in some places spanned 41.4 kilometers.

The canals, illustrated in Figure 1.21, were constructed over a period of hundreds of years, and were thought to have ceased in their functioning between 1100 and 1450 A.D. Archaeologists from the University of Arizona believe that great floods, rather than drought, might have impaired the functioning of the canals, and thereby doomed the Hohokam civilization. Other experts believe that the demise of this civilization was the result of a 23-year drought. In either case, water resources are vital to the survival and continued development of the state.

The state is divided into five planning areas and four active management areas in regards to hydrologic classification and management of both surface- and

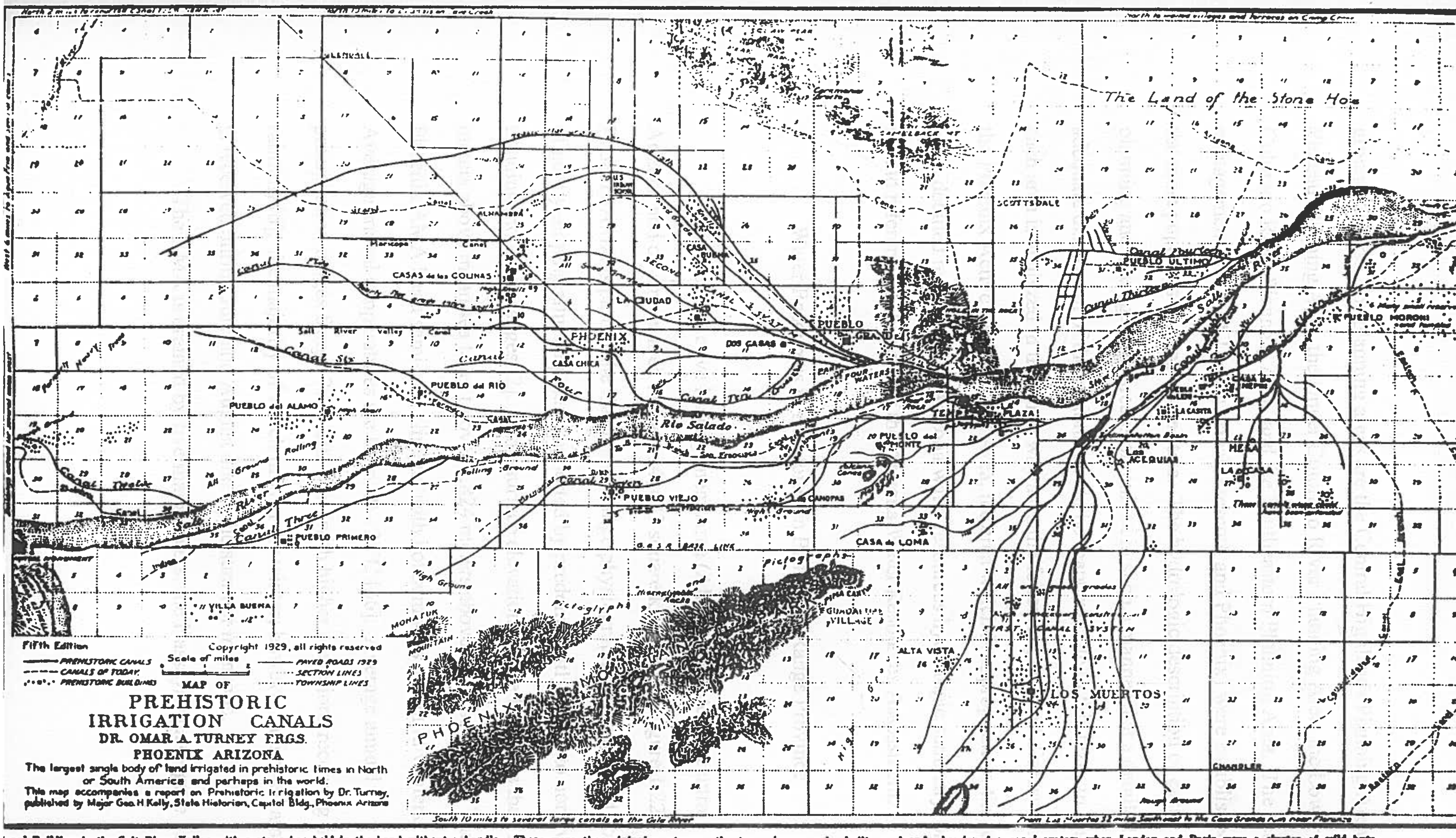


Figure 1.21: Arizona's Ancient Irrigation Network

ground-waters. The planning areas are the Central Highlands Planning Area, the Plateau Planning Area, the Upper Colorado River Planning Area, the Lower Colorado River Planning Area, and the Southeastern Planning Area. The active management areas (of Tucson, Pinal, Prescott, and Phoenix) were established in the most populous regions of the state. The hydrologic description of each planning and management area is organized in such a manner that a detailed and adequate discussion of the regions would be inappropriate to this text. In essence, each area is analyzed in the same way as is the following detailed discussion of the Phoenix Active Management Area, the area which is appropriate to the text. For a detailed review of the Arizona water resources hydrologic summary, one should reference Volume II of the Arizona Water Resources Assessment.

Water Resources in the Northern Basin and Range Province

The Phoenix Active Management Area (AMA) is located in central Arizona and covers an area of over 14, 623 square kilometers (Figure 1.22). The Phoenix AMA is part of the Basin and Range physiographic province and consists of gently-sloping alluvial plains supported by predominantly north- to northwest-trending mountain ranges [2]. Land-surface elevations range from less than 243 meters above mean sea level to over 1,824 meters above mean sea level. The Phoenix AMA has a semi-arid climate, with hot summers and mild winters. Average annual temperatures are from 20 - 21°C [36]. Average annual precipitation ranges from 177 to 203 mm (with higher elevations receiving more rainfall) [6], the majority of which falls in the winter; however, a limited amount is received during July and August due to the summer monsoon.

The AMA is drained by five major rivers: the Hassayampa (Figure 1.23),

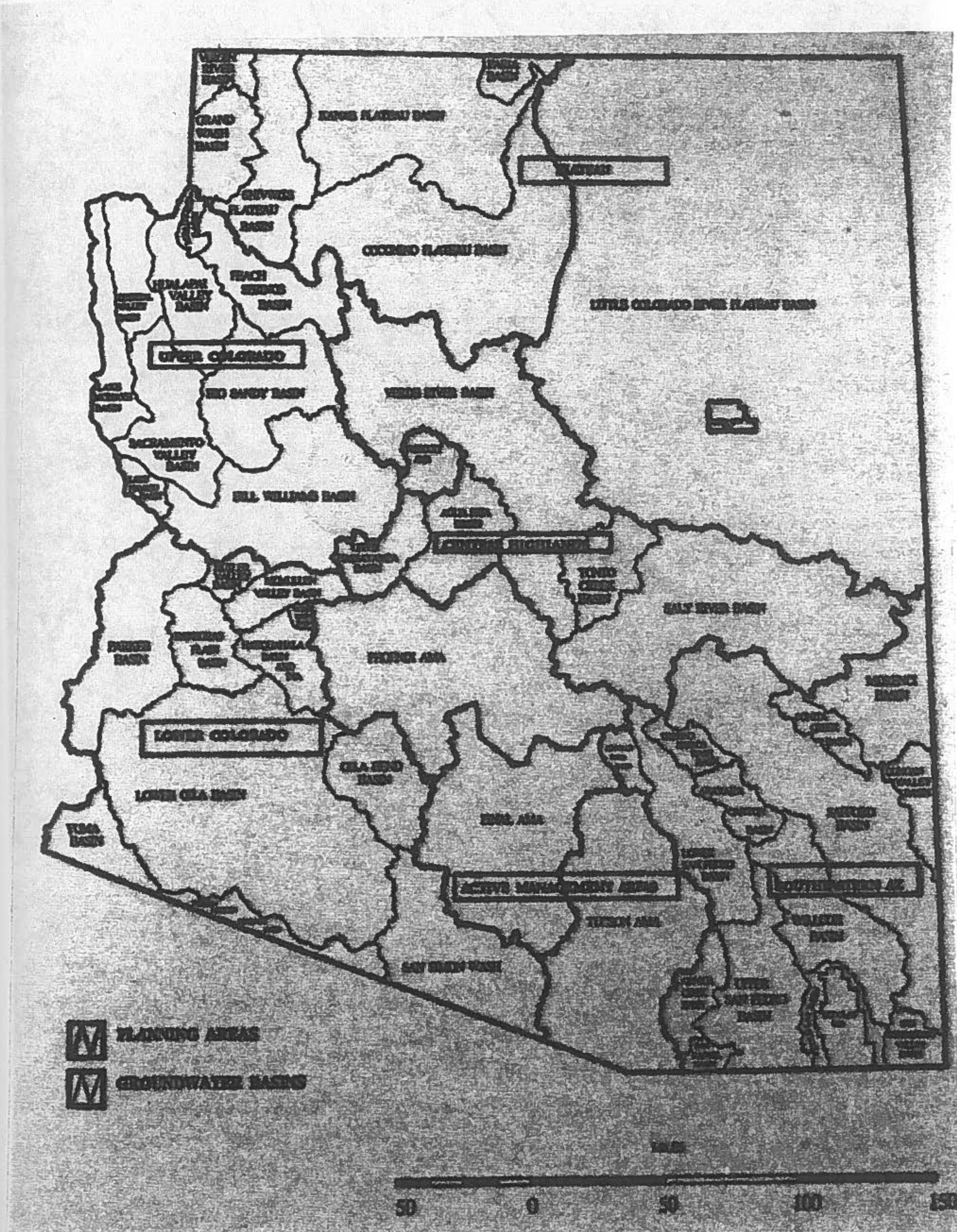


Figure 1.22: Arizona's Planning Areas and Groundwater Basins

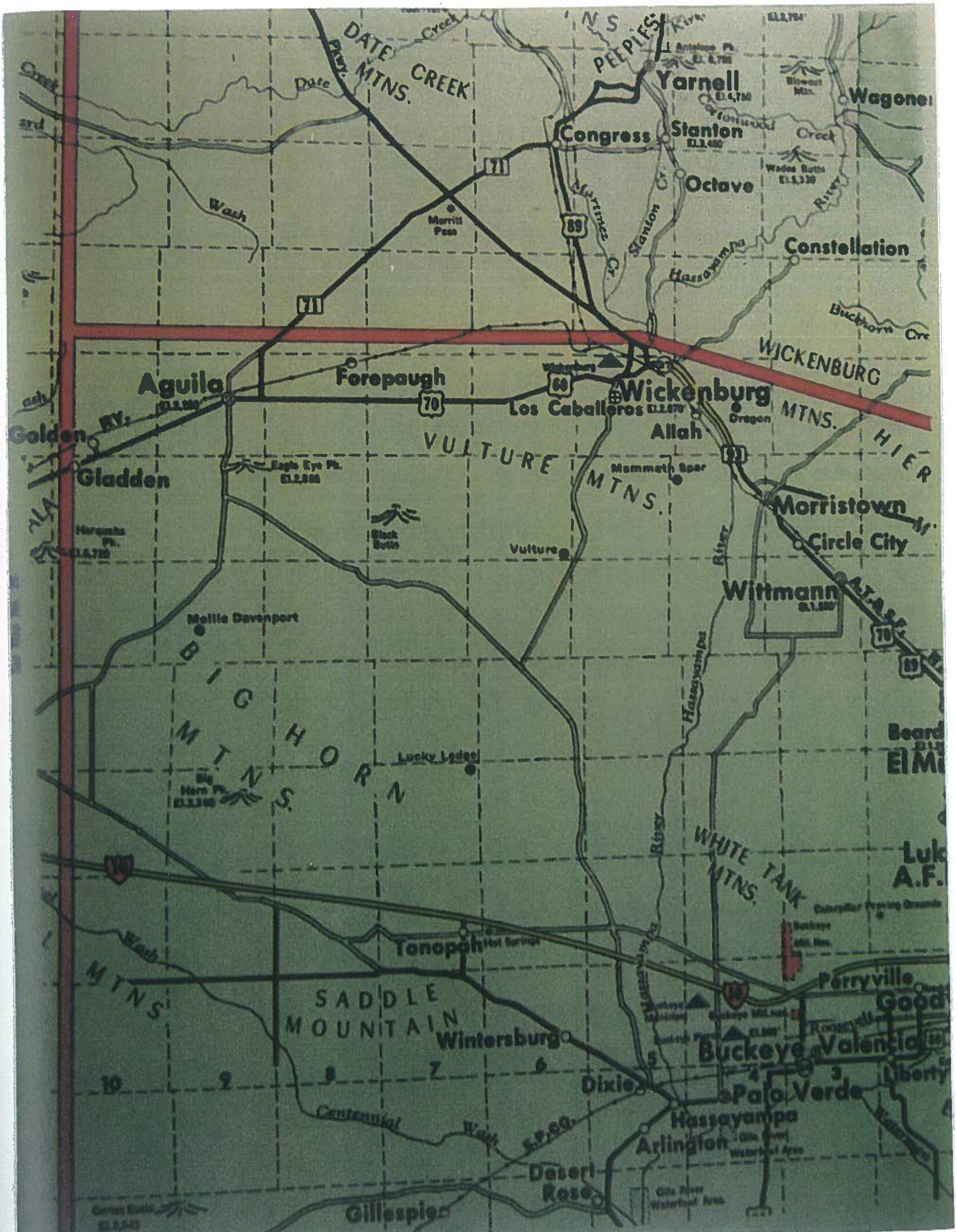

DATE CREEK MTNS.
Date Creek
Yarnell
Wagoner
Congress
Stanton
Octave
Constellation
Hassayampa
Buckhorn Cr.
WICKENBURG MTNS.
Wickenburg
Aguila
Forepaugh
Los Caballeros
Allah
Golden
Gladden
VULTURE MTNS.
Mammoth Spur
Morristown
Circle City
Vulture
Black Butte
Wittmann
Mollie Davenport
BIG HORN MTNS.
Lucky Ledge
WHITE TANK MTNS.
Tonopah
SADDLE MOUNTAIN
Wintersburg
Perryville
Buckeye
Valencia
Palo Verde
Dixie
Hassayampa
Arlington
Desert Rose
Gillespie
Centennial Wash

Figure 1.23

Salt, Gila, Verde, Agua Fria (Figure 1.24). The Salt River below Granite Reef Dam (Figure 1.24) is ephemeral, flowing only in response to local flooding and releases from upstream reservoirs. The Agua Fria and Hassayampa Rivers are also ephemeral. Below the confluence with the Salt River, the Gila River flows perennially due to effluent discharge from the City of Phoenix 91st Avenue wastewater treatment plant. The Verde River within the AMA is also perennial. Although the five major rivers serve as a source of groundwater recharge, only the Gila, Salt, Verde, and Agua Fria are used for direct surface water supply.

The AMA consists of seven groundwater sub-basins: East Salt River Valley (ESRV), the West Salt River Valley (WSRV), Hassayampa, Rainbow Valley, Fountain Hills, Lake Pleasant, and Carefree. The hydrogeology of each sub-basin is discussed in each of the following sections.

East Salt River Valley Sub-basin

The East Salt River Valley sub-basin (ESRV) is located in the eastern part of the Phoenix AMA and covers an area of approximately 4,429 square kilometers (Figure 1. 22). The ESRV, a gently-sloping alluvial plain, encompasses the eastern part of the Phoenix metropolitan area, including the cities of Scottsdale, Tempe, Mesa, Chandler, and Gilbert (Figure 1.24). It is bordered in the north, east and west and east by hills and mountains. Depth to bedrock ranges from less than 30 meters near the basin margins to approximately 1,520 meters in the Paradise Valley area and over 10,000 feet southeast of Gilbert [7].

Three hydrogeologic units are recognized within the basin fill sequence. The upper unit consists of some sand and gravel with a small amount of interbedded silt and clay. The unit is coarser near the Salt and Gila Rivers. The

NATIONAL
FOREST
Crown King
Wagoner
Bumble Bee
Horsethief Basin
TONTO
BRADSHAW MTNS.
FOREST
Black Canyon City
Rock Springs
NEW RIVER MTNS.
Champie
Castle Hot Springs
HIEROGLYPHIC MTNS.
New River
Lake Pleasant
Lake Pleasant Resort
Seven Spgs
Camp Creek
Spur Cross
Cave Creek
Carefree
Brown's
PARADISE VALLEY STATE REFUGE
Moore's
Churchill Adobe
McDOWELL MTNS.
Pemberton
Beardsley
Surprise
El Mirage
Sun City
Youngtown
Cactus
Paradise Valley
Peoria
Luke A.F.B.
Glendale
Litchfield Park
Phoenix
Mesa
Cashion
Tolleson
Goodyear
Avondale
Tempe
Norton
Laveen
Guadalupe
Gilbert
West Chandler
Falfa
Higley
SIERRA ESTRELLA
GILA RIVER
St. Johns
Komatke
Chandler

Figure 1.24

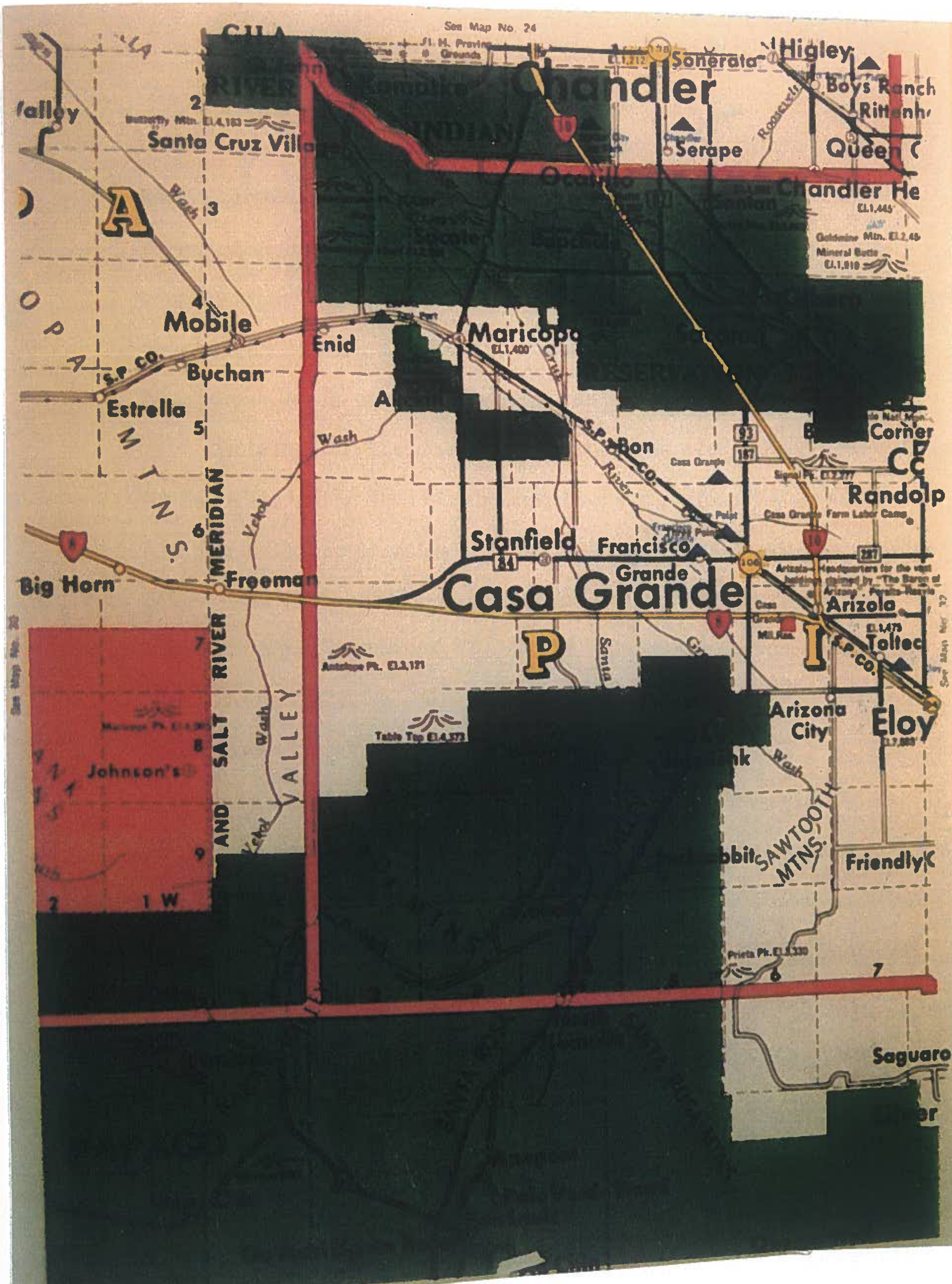
upper unit ranges in thickness from less than 30 meters near the basin margins to over 106 meters in some parts of the basin [7].

The middle unit consists predominantly of silt and clay with some interbedded sand and gravel. Near the basin margins, the unit is coarser, and typically cannot be distinguished from the upper and lower units. The middle unit ranges in thickness from less than 30 meters near the basin margins to over 547 meters southeast of Gilbert [7]. The lower unit consists mainly of conglomerate near the basin margins, becoming finer toward the center of the basin. The unit ranges in thickness from less than 30 meters near the basin margins to over 2,700 meters southeast of Gilbert [7].

Groundwater enters the ESRV as underflow from the Lake Pleasant sub-basin (Figure 1.24), the Eloy sub-basin, east of the Santan Mountains, and between the Santan and Sacaton mountains (Figure 1.25). Prior to development, groundwater flowed toward and along the Salt and Gila Rivers, and into the West Salt River Valley sub-basin (WSRV), between the Papago Buttes and the South Mountains (Figure 1.24). Groundwater also flowed between the South Mountains and Sierra Estrella Mountains (Figure 1.24), through the northern part of the Pinal Active Management Area [1].

Today, most of the groundwater flows toward three large cones of depression created by groundwater over pumping for agricultural or municipal use. These areas are located near Scottsdale and Mesa. Although groundwater still flows into the WSRV south of South Mountain, some of the underflow has been diverted due to groundwater pumping in the Maricopa-Stanfield sub-basin to the south.

Sources of groundwater recharge include natural recharge from flood flows in ephemeral streams, mountain front recharge, and incidental recharge



See Map No. 24
Higley
Boys Ranch
Chandler
Serape
Santa Cruz Vill
Mobile
Enid
Maricopa
Buchan
Estrella
Bon
Randolp
Stanfield
Francisco
Grande
Casa Grande
Freeman
Big Horn
Arizola
Toltec
Arizona City
Eloy
Johnson's
MERIDIAN
RIVER
SALT
AND
VALLEY
SAWTOOTH MTNS.
Friendly
Saguaro

Figure 1.25

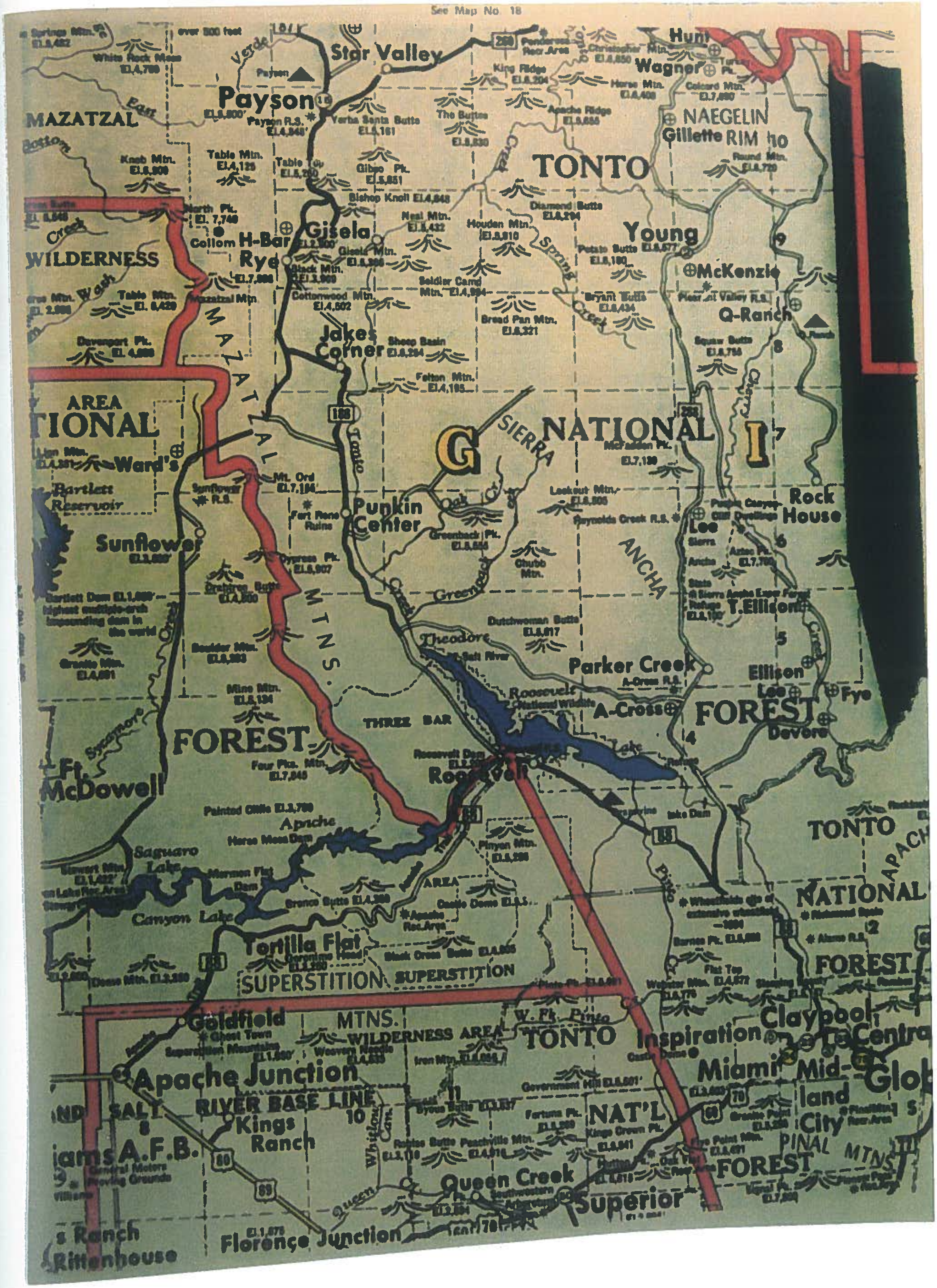
from agricultural and urban irrigation, canals, and artificial lakes. The primary source of groundwater discharge is groundwater pumping.

Groundwater development began in the late 1800's, with the digging of shallow irrigation wells along the Salt and Gila Rivers [42]. As agronomy expanded, groundwater development increased. To date, hundreds of high-capacity irrigation wells have been drilled, many to depths of over 300 meters, to augment surface-water supplies. In addition, many deep, high-capacity wells have been drilled for municipal and industrial use.

In 1915, 1,845 hectare-meters of groundwater were pumped from wells in the Salt River Valley. By 1942, the annual volume of groundwater withdrawn had increased to approximately 123,000 hectare-meters. Groundwater pumpage peaked in the 1950's, with approximately 282,900 hectare-meters per year withdrawn from 1952 to 1958. By 1982, annual pumpage had decreased to approximately 135,300 hectare-meters. Approximately 37, 502 hectare-meters of groundwater were pumped from the ESRV alone in 1990 [8].

As a result of groundwater development, water levels have declined significantly, particularly in areas impacted by pumping for agricultural irrigation or municipal supply. Water levels declined between 1923 to 1976 by an average of 114 meters [38]. Water levels rose over most of the ESRV from 1976-1983 due to heavy runoff and abundant surface water supply. The volume of groundwater in storage currently is estimated at 8,118,000 hectare-meters to a depth of 365 meters [7]. Depth to groundwater was on average 106 meters in 1983. In the Queen Creek area (Figure 1.26) groundwater pumping has resulted in land subsidence of an average of 1.37 meters [61].

Groundwater-quality data indicate that the majority of the groundwater in the ESRV is suitable for most uses, including domestic use. However, poor



See Map No. 18
Star Valley
Payson
MAZATZAL
Hunt
Wagner
NAEGELIN
Gillette RIM
TONTO
Young
Gisela
H-Bar
Rye
McKenzie
Q-Ranch
WILDERNESS
Jakes
Corner
AREA
TIONAL
NATIONAL
SIERRA
Ward's
Bartlett
Reservoir
Sunflower
MAZATZAL
MTNS.
Punkin
Center
ANCHA
Rock
House
T.Ellison
Theodore
Parker Creek
A-Cross
Ellison
Fye
FOREST
Devore
THREE BAR
FOREST
Roosevelt
Ft.
McDowell
Apache
Saguaro
Lake
Canyon Lake
Tortilla Flat
SUPERSTITION
SUPERSTITION
MTNS.
WILDERNESS AREA
Goldfield
Apache Junction
SALT
RIVER BASE LINE
Kings
Ranch
A.F.B.
TONTO
Inspiration
Claypool
Miami
Mid-
land
City
NAT'L
FOREST
PINAL
MTNS
Queen Creek
Superior
Florence Junction
s Ranch
Rittenhouse
TONTO
NATIONAL
FOREST
APACH

Figure 1.26

quality does restrict groundwater use in many areas. Degradation of groundwater in the Phoenix metropolitan area has caused considerable concern because groundwater is an important source of drinking water supplies. Contamination from various sources has resulted in elevated levels of total dissolved solids, sulfates, nitrates, volatile organic compounds (VOC's), pesticides, and heavy metals in groundwater. Industrial point sources, agriculture, dry well injection, unregulated landfills, and underground storage tanks are the major activities that have led to groundwater contamination not only in the ESRV, but in all Phoenix AMA sub-basins [5]. The majority of the poor-quality groundwater is in the upper unit due to the fact that contaminants typically infiltrate from the surface. Many wells in the Phoenix area cannot be used because of this contamination [5].

West Salt River Valley Sub-basin

The West Salt River Valley sub-basin (WSRV) is located in the western part of the Phoenix AMA and covers an area of approximately 3,445 square kilometers (Figure 1.22). The WSRV, a broad, gently-sloping alluvial plain, encompasses the western part of the Phoenix metropolitan area, including the cities of Phoenix, Glendale, Peoria, Tolleson, and Avondale (Figure 1.24).

It is bounded on the north, east, south and west hills and mountains. Depth to bedrock ranges from less than 30 meters near the basin margins to over 3,000 meters in the Luke Air Force Base (Figure 1.24) [7].

Three hydrogeologic units recognized within the basin-fill sequence [16]. The upper unit mainly consists of sand and gravel with some interbedded silt and clay. The unit becomes coarser near the Salt and Gila Rivers. The upper unit ranges in thickness from less than 30 meters near the basin margins to over 152 meters in the Luke Air Force Base area [7].

The middle unit predominantly consists of silt and clay with some interbedded sand and gravel. Near the basin margins, the unit is coarser, and typically cannot be distinguished from the upper and lower units. The middle unit ranges in thickness from less than 30 meters near the basin margins to over 395 meters southwest of Glendale [7]. The lower unit mainly consists of coarse-grained conglomerate near the basin margins, becoming finer-grained toward the center of the basin. The unit ranges in thickness from less than 30 meters near the basin margins to over 3,040 meters southwest of Glendale [7]. A large salt body, known as the Luke salt body, lies in the WSRV, southeast of the Luke Air Force Base, and occurs at a depth of 268 meters to over 1,824 meters. Geohydrologic data indicate that the upper part of the salt body has a significant local effect on groundwater salinity.

Groundwater enters the WSRV as underflow from the Lake Pleasant sub-basin, the northern part of the Hassayampa sub-basin, and the Maricopa-Stanfield sub-basin. Prior to development, groundwater flowed toward and along the Salt and Gila Rivers, and into the southern part of the Hassayampa sub-basin near Arlington [1]. In addition, there was groundwater inflow from the ESRV between the Papago Buttes and the South Mountains. Although groundwater still flows from the WSRV into the southern part of the Hassayampa sub-basin, most of the groundwater flows toward two large cones of depression created by groundwater pumping for agricultural or municipal use.

Sources of groundwater recharge include natural recharge from flood flows in ephemeral streams and along mountain fronts, and incidental recharge from agricultural and urban irrigation, canals, effluent, and artificial lakes. The primary source of groundwater discharge is groundwater pumping. Additional sources of groundwater discharge include phreatophytes distributed along the Gila River and groundwater discharge to the lower reaches of the Gila River [7].

Groundwater development in the WSRV is identical to that in the ESRV, as are groundwater pumpage estimates. Approximately 59,175 hectare-meters of groundwater were pumped from the WSRV alone in 1990 [8]. As a result of groundwater development, water levels have declined significantly, particularly in areas impacted by excessive pumping for agricultural irrigation or municipal supply. From 1923 to 1977, water levels declined by more than 91 meters near Luke Air Force Base and in the Deer Valley area (Figure 1.24) [58]. Water levels rose over most of the WSRV from 1976 to 1983 because of heavy runoff and abundant surface water supply. The volume of groundwater in storage currently is estimated at 7,257,000 hectare-meters to a depth of 365 meters [7].

Depth to groundwater in 1983 ranged from less than 15 meters to over 152 meters below land surface [44]. In the Buckeye area, shallow groundwater conditions have caused waterlogging problems creating detrimental effects on crops [49]. Shallow groundwater conditions in the Buckeye area were even documented prior to development. In spite of extensive groundwater development, waterlogging problems still persist due to the high volume of treated effluent discharged into the Salt River by the City of Phoenix 91st Avenue wastewater treatment plant. Groundwater pumping has resulted in land subsidence and the development of earth fissures (Figure 1.27) in an area of approximately 363 square kilometers near Luke Air Force Base [61]. This area is reported to have subsided more than 0.9 meter by 1977. The Luke area is characterized by extensive historic groundwater withdrawals and water level declines.

Groundwater quality data are similar to that of the ESRV. Industrial and

Figure 1.27: Earth Fissure in Arizona

agricultural pollution are concerns within this area. Chemical contamination exceeds the standards set by the Environmental Protection Agency, a federal organization. Nitrate and sulfate contamination are highly prevalent due the agricultural environment of the region.

Hassayampa Sub-basin

The Hassayampa sub-basin is located in the western half of the Phoenix AMA and covers an area of approximately 3,108 square kilometers (Figure 1.22). The sub-basin includes the Hassayampa Plain in the north, which consists largely of undeveloped desert land, and the lower Hassayampa area in the south, which consists of both agricultural land and undeveloped desert.

The Hassayampa sub-basin is a gently-sloping alluvial plain bounded on the north, east, south and west by hills and mountains [46]. The area is drained by the ephemeral Hassayampa River (Figure 1.23), which enters the sub-basin in the northeast and joins the Gila River. The Gila River, which flows perennially with effluent from the west Phoenix metropolitan area, crosses the southeastern tip of the sub-basin.

Depth to bedrock ranges from approximately 15 meters near the basin margins to over 365 meters near the center of the basin [9]. The basin-fill sequence in this part of the sub-basin (which consists of undifferentiated gravel, sand, silt, and clay), is not well understood due to a lack of geologic data [16].

The lower Hassayampa area includes the Centennial Wash Area (Figure 1.23). Depth to bedrock in the lower Hassayampa area ranges from a couple of meters near the basin margins to over 365 meters in the central part of the area [46]. The basin-fill sequence in this region consists of three hydrogeologic units designated as the upper, middle, and lower alluvium. The upper unit is 9 to 18 meters thick and consists of silty sands and gravelly sands with clay and silty clay lenses. The middle unit, which is 70 to 91 meters thick, consists of clay and silty clay with clayey silt, clayey sand, and silty sand lenses. The lower unit, from 30 to more than 304 meters thick, consists of unconsolidated silty sand, sand, and gravelly sand, and moderately- to well- consolidated alluvial fan deposits. Hydraulic-conductivity and specific-yield data are not available for the lower Hassayampa area; however, the regional aquifer will yield from a few to over 7,560 liters per minute of water to properly constructed wells [46].

Groundwater enters the Hassayampa Plain from the northeast, with the hydraulic gradient supported by infiltration from the Hassayampa River. Most of the groundwater generally flows south into the lower Hassayampa area. After passing the bedrock constriction between the Belmont and White Tank Mountains, groundwater flows southwest toward a cone of depression in the Centennial Wash area. This cone was created by groundwater pumping for agricultural irrigation. Groundwater also enters the southeastern part of the lower Hassayampa area as underflow from the southern part of the West Salt River Valley sub-basin. Most of this water is captured by the cone of depression in the Centennial Wash area [46].

Sources of groundwater recharge include stream bed recharge from the Gila and Hassayampa Rivers and ephemeral streams, mountain front recharge, and incidental recharge from agricultural irrigation and canals. The primary source of groundwater discharge is groundwater pumping.

Groundwater development in the Hassayampa Plain has been minimal, with the exception of a few wells for livestock and domestic use. However, in the lower Hassayampa area, extensive agricultural development (supported mainly with groundwater pumpage) began in the early 1950's. Approximately 9,720 hectares of land were under cultivation by 1960 [63]. Groundwater pumpage in the Hassayampa sub-basin is almost exclusively confined to the lower Hassayampa area. Groundwater pumpage in the Hassayampa Plain is less than 61 hectare-meters per year and is therefore considered insignificant. In contrast, the pumpage in the lower Hassayampa area averaged 10,209 hectare-meters per year (from 1973 through 1981), the vast majority of which can be attributed to agricultural irrigation. Approximately 5,190 hectare-meters of groundwater were pumped in 1990 [8].

Water levels are significantly declining in agricultural areas supported by groundwater. From the mid-1950s through 1982, water levels declined by as much as 27.4 meters in the Centennial Wash area [63]. In Arlington Valley, (Figure 1.23) by contrast, groundwater levels have remained stable or risen, because of surface-water availability, recharge from the Gila River, and underflow from the West Salt River Valley sub-basin [46]. Depth to groundwater in the Hassayampa sub-basin in 1982 averaged 103 meters below the land surface [31].

Groundwater quality data for the region indicate that the majority of the water is suitable for most uses. Nine percent of the samples analyzed did not pass the minimal contamination standards set by the Environmental Protection Agency.

Rainbow Valley Sub-basin

The Rainbow Valley sub-basin is located in the southern portion of the Phoenix AMA and covers an area of approximately 1,087 square kilometers (Figure 1.22). The sub-basin is a gently-sloping alluvial plain consisting mainly of undeveloped desert land in the south and agricultural land in the north.

Depth to bedrock in the Rainbow Valley sub-basin ranges from a couple meters near the basin margins to a maximum verified depth of over 384 meters in the north-central part of the basin [73]. Regional gravity data indicate that the deepest part is located in the central part of the basin, where maximum depth may exceed 2,918 meters [53]. The basin-fill sequence comprising the regional aquifer consists of poorly-sorted gravel, sand, silt, and clay [73]. The lithology of the regional aquifer is not well-defined due to the lack of geologic data.

Groundwater in the southern part of the sub-basin generally flows toward the northwest [22, 63]. In the northern part of the sub-basin, all groundwater flows toward an extensive cone of depression created by groundwater over pumping for agricultural irrigation.

Prior to groundwater development, groundwater may have entered the basin as underflow from the Maricopa-Stanfield sub-basin (Figure 1.25) [73]. A divide has been created between the two sub-basins due to water-level declines caused by extensive groundwater development in the Maricopa-Stanfield area.

Sources of groundwater recharge include stream bed recharge from flood flows in associated washes, mountain-front recharge, and incidental recharge from agricultural irrigation. The primary source of groundwater discharge is groundwater pumping. Groundwater development for agricultural irrigation in the Rainbow Valley sub-basin began in the early 1950's. In 1952, there were only 418 hectares of land under cultivation [74]. However, by 1961, the amount of land under cultivation had increased to about 6,480 hectares [73]. This level of cultivation has remained fairly constant as recently as 1982 [63].

Almost all groundwater pumpage in the Rainbow Valley sub-basin occurs in the developed agricultural area of the north. A total of 195, 078 hectare-meters of groundwater were pumped from 1948 through 1981 [63]. Pumpage has remained relatively constant since about 1960 [8].

Water levels began declining in the early 1950's, and by 1982, water levels had declined by as much as 60 meters in the developed agricultural area of the north [63]. Depth to groundwater in the Rainbow Valley sub-basin is on average 78 meters [63].

Groundwater quality data in the northern agricultural area indicate that most of the groundwater in this part of the sub-basin is unsuitable for domestic use and is only marginally suitable for agricultural irrigation.

Fountain Hills Sub-basin

The Fountain Hills sub-basin is located in the northeastern part of the Phoenix AMA and covers an area of approximately 932 square kilometers (Figure 1.22). The Fort McDowell Indian Reservation is included in this sub-basin, which covers approximately 103 square kilometers along the lower part of the Verde River, the community of Fountain Hills in the southwest, and the development of Rio Verde in the northwest (Figure 1.24). The Fountain Hills sub-basin is an extensively dissected alluvial plain. The sub-basin is drained by the lower part of the Verde River, a perennial river regulated by Bartlett Dam (Figure 1.24).

Depth to bedrock in the Fountain Hills sub-basin ranges from a couple of meters at the basin margins to over 365 meters near the center of the basin [57]. According to Oppenheimer, the maximum depth may exceed 1,459 meters [53]. The regional aquifer consists of two distinct hydrogeologic units. The unconsolidated alluvium that underlies the modern floodplain of the Verde River.

This hydrogeologic unit is approximately 1.6 kilometers in width and at least 27 meters thick. The alluvium consists of gravel and sand, with flood plains composed of sandy silt [48].

Sources of groundwater recharge include stream bed recharge from the Verde and Salt Rivers and their tributaries, as well as mountain-front recharge. Sources of groundwater discharge include groundwater pumping, discharge to the Verde and Salt Rivers, and usage by phreatophytes distributed along the Verde and Salt Rivers. Groundwater development in the Fountain Hills sub-basin has been minimal. Almost all groundwater pumpage occurs in the southern portion of the sub-basin. Approximately 320 hectare-meters of groundwater were pumped in 1990 [8]. Long-term water-level records are not available for the area; however, available information suggests that water levels have not been significantly impacted by groundwater development. Depth to groundwater in 1982 was on average 76.9 meters below land surface [56].

Limited groundwater quality data indicate that most of the groundwater in the Fountain Hills sub-basin is suitable for most uses, including domestic use.

Lake Pleasant Sub-basin

The Lake Pleasant sub-basin is located in the northern part of the Phoenix AMA and covers an area of approximately 621.6 square kilometers (Figure 1.22). The sub-basin is a relatively small, gently-sloping alluvial plain consisting of undeveloped desert land, with the town of New River in the northeast and a small agricultural area along the Agua Fria River in the southwest (Figure 1.24).

Depth to bedrock in the Lake Pleasant sub-basin ranges from a couple of meters near the basin margins to over 243 meters near the center of the basin [20].

The lithology of the basin-fill sequence is not well-defined due to a lack of subsurface data. Well yields range from less than 3.78 to as high as 6,048 liters per minute [45]. Most of the New River area is drought-sensitive and groundwater withdrawals in certain areas have depleted the limited supply [9].

With the exception of the New River area, wells are relatively sparse, therefore, groundwater conditions are not clearly defined. The general direction of groundwater flow, is from north to south [56], and has probably remained relatively unchanged since the predevelopment period. This fact suggests that the Lake Pleasant sub-basin is hydraulically connected with the West Salt River Valley (WSRV) and East Salt River Valley (ESRV) sub-basins. Sources of groundwater recharge include stream bed recharge from the Agua Fria River, New River, and Skunk Creek, and mountain-front recharge. The primary source of groundwater discharge is groundwater pumping.

Groundwater development in the Lake Pleasant sub-basin has been minimal. It is currently pumped by numerous domestic wells, mainly near the town of New River, and by a few small, private water companies. Approximately 36.9 hectare-meters of groundwater were pumped in 1990 [8].

Depth to groundwater in 1982 was on average 59 meters below the land surface [56]. In 1983, limited groundwater quality data indicate that most of the groundwater in the Lake Pleasant subbasin is suitable for most uses, including domestic use.

Carefree Sub-basin

The Carefree sub-basin is located in the northeastern part of the Phoenix AMA and covers an area of approximately 363 square kilometers (Figure 1.22). The sub-basin includes the communities of Carefree and Cave Creek in the south (Figure 1.24), and mainly consists of mountainous, undeveloped desert in the north. The groundwater-bearing portion of the sub-basin is a small, alluvial plain approximately 13.7 kilometers long and four kilometers wide. This area is located in the southern part of the sub-basin, and is drained by Cave Creek, a small ephemeral stream which heads in the hills east of New River Mesa and flows south across the western part of the sub-basin.

According to Pewe and Doorn [55], the Carefree sub-basin is relatively shallow (approximately 608 meters), and is filled with older, partially-consolidated to consolidated sedimentary rocks. Approximately 60% of the basin is a significant source of groundwater.

The Carefree Formation is underlain by volcanic rocks, which do not yield significant amounts of water. However, underlying the volcanic rocks is a zone of weathered granite that may exceed 152 meters in thickness in some places. Well yields as high as 2,268 liters per minute have been recorded in the weathered granite, making this a potential future source of groundwater [55].

Groundwater development began in the 1960's due to the need for golf course irrigation and to support the expanding population [13]. Groundwater currently is used to support a population of approximately 4,500 and to irrigate six golf courses. Groundwater pumpage steadily has increased from 24.6 hectare-meters in 1961 to over 418 hectare-meters in 1990 [8].

Water levels began declining in the early 1960's, with the advent of groundwater development. In the center of the basin, a cone of depression has formed as a result of heavy pumping associated with the golf courses [14]. Water-level declines in this area, as reported by Bernier (1992), exceed 3 meters per year. In 1991, depth to groundwater in the Carefree sub-basin in 1991 ranged from less than 9 meters below land surface near Cave Creek to over 118 meters below land surface in the eastern part of the basin [14].

Groundwater-quality data indicate that most of the groundwater in the Carefree sub-basin is suitable for most uses, including domestic use.

Surface Water

Although the surface water supplies of the Phoenix AMA serve as a source of groundwater recharge, only the Gila, Salt, Verde, and Agua Fria Rivers are used directly for water supply. The chemical quality of the water in these rivers generally is good. Reported values for total dissolved solids, sulfate, nitrate, and metals are all well within primary and secondary standards, with the exception of the Gila River. The Gila River is characterized by sulfate values of around 500 milligrams per liter (mg/1), twice the secondary maximum contaminant level of 250 mg/l. High sulfate levels in the Gila River may be caused by effluent discharged from the City of Phoenix wastewater treatment plants.

The lower Salt River through Phoenix and the Gila River, from its confluence with the Salt to Painted Rock Reservoir (outside the Phoenix AMA), is contaminated with pesticides, metals, inorganics, and nutrients, and has low dissolved oxygen. Gillespie and Painted Rock Dams appear to act as contaminant sinks and exhibit high levels of pesticides, boron, and organochlorines [5]. Bioaccumulation of toxic substances in contaminated sediments presents a risk to fish and wildlife, and may pose a risk to human health. DDE and toxaphene have been found in fish tissues at Gillespie and Painted Rock Dams where they pose a threat to wildlife resources of the lower Gila River drainage [36]. Pesticide contamination in the Salt and Gila Rivers represents some of the most significant contaminant sites in the western United States. Agricultural-return flows and several municipal discharges feed these rivers.

CHAPTER 2:

ENVIRONMENTAL GEOGRAPHY OF WATER RESOURCES IN HUNGARY AND ARIZONA

INTRODUCTION

"One of the greatest achievements of the last quarter of the 20th century has been drawing attention to the problems of environmental concerns" [70]. The productivity of any given area is determined by a variance of interactions (natural and man-made), the most important of these is of an ecological nature, and that is climate [17]. As our awareness of ecological issues has increased, one of the main issues to rise to the top has been that of climate. The bioproductivity supply of the human food chain is dependent upon solar energy, nutrient supplies, and water. Temperature has an effect, and the effects of precipitation are dependent upon soil-water relationships and supplies. The importance of these relationships are not newly identified, as can be seen by the literature which addresses them dating back to 1968 [12, 21, 40, 68]. However, the issue has taken on increasing importance within the past decade. The United Nations is presently reporting on the suggestions and decisions of the Intergovernmental Panel on Climate Change (IPCC). This panel has agreed that "the balance of evidence suggests a discernible human influence on global climate." This quote is an excerpt from the second IPCC Assessment which was adopted in Rome, Italy by the representatives of the world's governments in December 1995 [34]. This is in contrast to the panel's previous stance which concluded that climate change over the last few decades was potentially due to naturally occurring variability. The question no longer is whether climate change will occur, but is how can we interact with the change, and ultimately what will happen as these changes progress towards an irreversible state.

Temperatures on Earth are increasing across the entire global surface. Part of this warming is due to the production of green house gases. Methane, for example, has increased 145% from its level before the industrial revolution [33]. Increase in gases such as these not only tend to warm the Earth's surface, but can produce other changes in the climate. "These changes can largely be attributed to the use of fossil fuels and agriculture" [33].

More than two-thirds of the Earth's surface is covered with water, which is accumulated in oceans, freshwater lakes, ponds, glaciers, and polar ice caps. The water cycle is of the utmost importance to life as we know it (Figure 2.1). Evaporation occurs as surface waters are warmed by the sun. The resulting water vapor rises to the atmosphere, where it cools, condenses and returns as precipitation, which is globally distributed via air currents.

When precipitation occurs over terrestrial areas, some of the water returns to oceans, lakes and streams in the form of runoff. The other portion percolates through the soil to the groundwater tables. Plant life retains approximately 1% of this percolated portion to generate the nutrients needed to begin the first trophic level of our global ecosystem. The other 99% of the water is transpired through leaves and stems in the form of vapor and then combines with other evaporated water in the atmosphere, thereby beginning the cyclical repeat.

The increase of global temperatures can have a negative effect on the balance of this cycle. Within the last century, the average global surface temperature has increased by approximately 0.3° C to 0.6°C. Recent years have

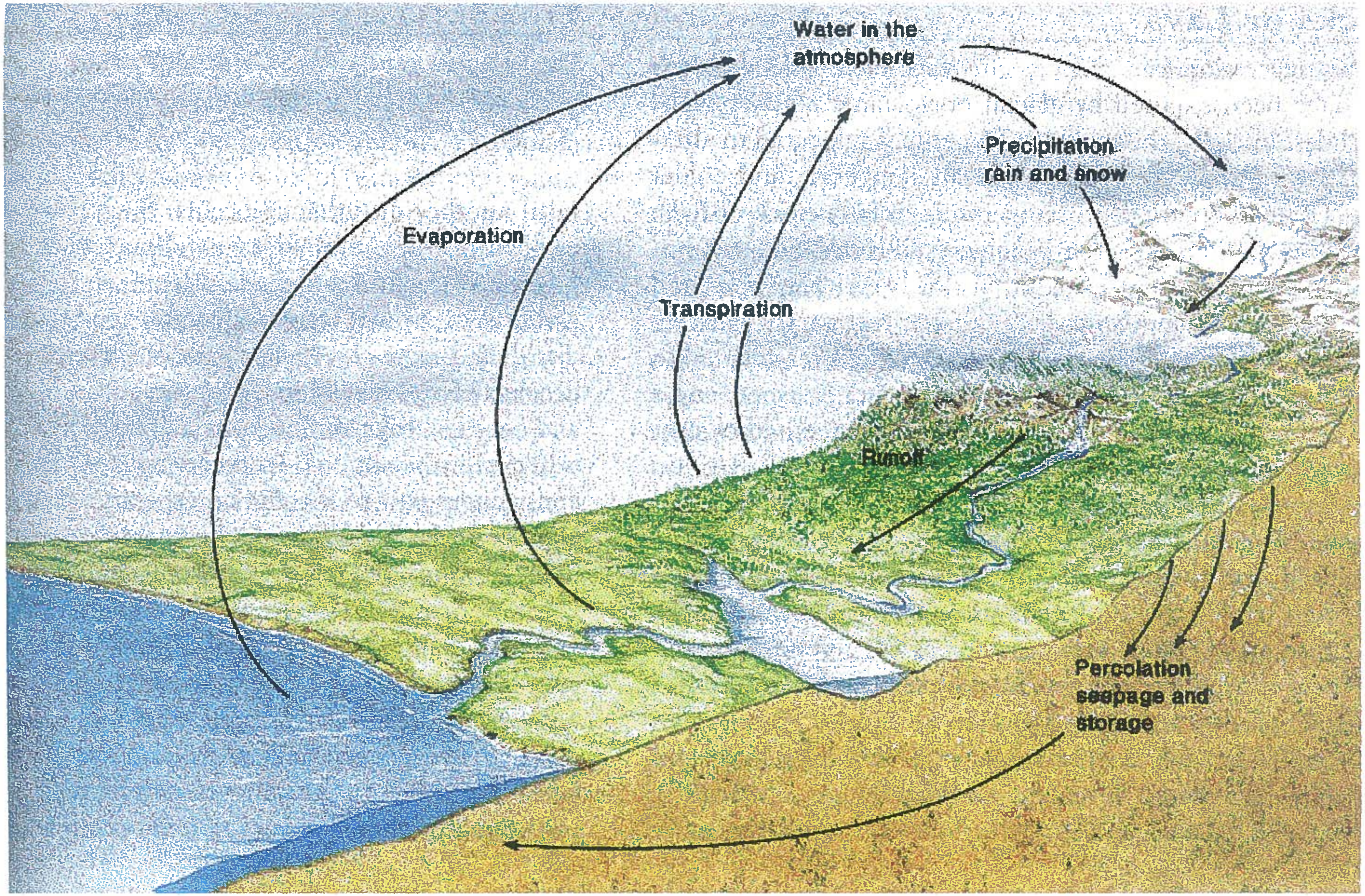


Figure 2.1: The Water Cycle

been amongst the warmest since 1860 [33]. Over the past century global sea level has risen by between 100 mm and 125 mm. This trend is expected to continue with an estimated projection of approximately 500 mm by the year 2100. Precipitation has also increased over high latitudes in the Northern Hemisphere and particularly in the winter.

Climatic changes have produced obvious effects on some geographical locations. In various parts of the U.S., the proportion of rain falling in heavy storms has increased, and many areas throughout the world are experiencing fewer frosts. As temperatures continue to rise, it is estimated by the IPCC that the average global surface temperature will rise by approximately 2°C between 1990 and 2100.

These estimates are considered to be applicable if policies to reduce carbon dioxide (CO_2) emissions from the current levels are not implemented. However, even with successful gaseous stabilization, the inertia of the oceans will set the stage for continuing temperature increases beyond the year 2100.

Temperature increase will also produce more vigorous hydrological cycles, resulting in increased evaporation and precipitation. As this occurs, the balance of the water cycle is destroyed. More severe floods will occur in some regions, and there will be an increase in droughts in others. In still others, there could be heavier rain storms. The delicate balance of the various ecocycles of the Earth can be altered from their state of flux. Evidence of past climates (partly by studying ice laid down in the polar ice-caps) suggests that the world's climate can change from one steady state to a very different one in a matter of a few decades [41]. It is believed by some scientists that global warming could give rise to a very deleterious shift in steady state.

The major impact of climatic change is the well-recognized depletion of the ozone layer (Figure 2.2). The Earth's climate is controlled by interrelated processes of the atmosphere, land, hydrosphere, and cryosphere, which provide the niches for the plethora of biological processes occurring. This interrelated global climate is driven by solar radiation. Approximately 25% of this radiation reaches the Earth's surface. Atmospheric gases, such as ozone, assist in the absorption of part of the sun's radiation within wavelengths which are harmful to life on Earth. Global concentrations of ozone are presently 10% lower than they were 25 years ago [52].

The Earth's surface emits infrared radiation to balance the incoming solar radiation, with the vast majority of this radiation being absorbed by the atmosphere. The majority of the atmosphere is composed of nitrogen and oxygen, neither of which absorb radiation of the infrared type. Carbon dioxide and water vapor (along with other minor greenhouse gases) are responsible for the natural trapping of infrared emission. The increase of greenhouse gases since industrialization has destroyed the natural balance of the stratospheric ozone, which absorbs a portion of the solar radiation wavelengths that are harmful to life on earth.

Carbon dioxide is one of the most important greenhouse gases. There has been a general increase of 27% of this gas since pre-industrial times, with this increase being attributed mainly to increased combustion of fossil fuels which are burned to meet production demands.

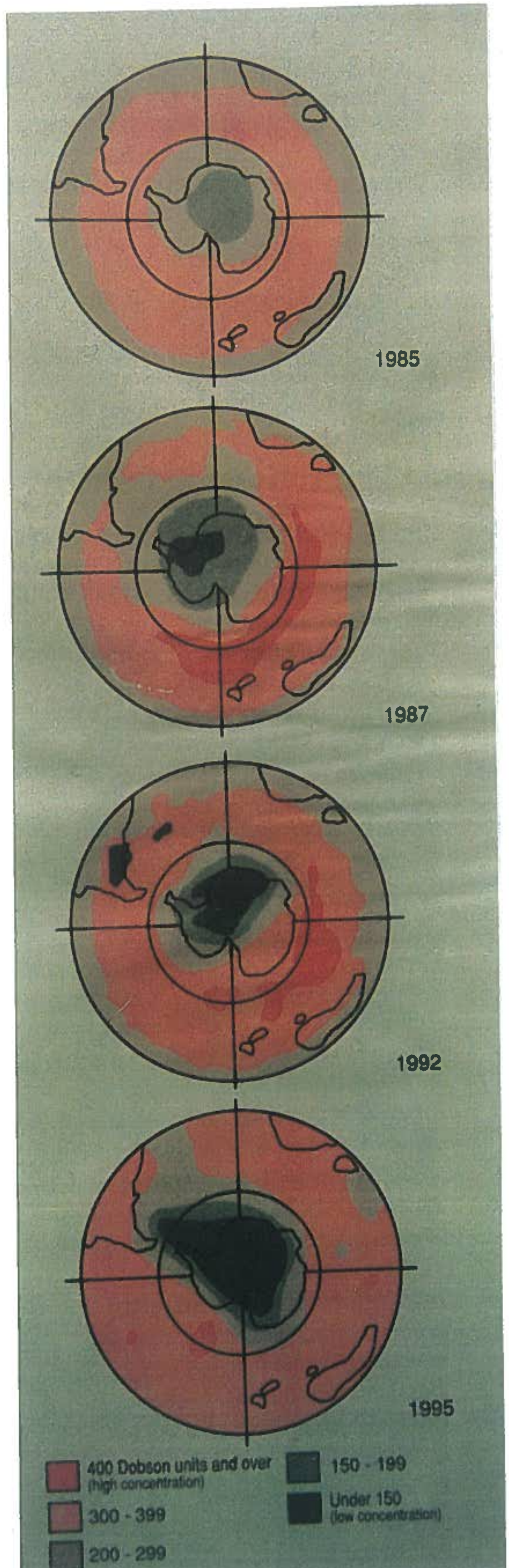


Figure 2.2: Reduction of the Ozone Layer

THE HUNGARIAN ENVIRONMENT: PAST TO PRESENT

The environmental scenario described above has been just as evident in Hungary as it has been in the rest of the world. As Twentieth Century industry developed in Hungary, so did the simultaneous combustion of fossil fuels. The event was particularly accentuated with the advent of socialist industrialization. The forced development of heavy industry, with great productivity as a priority, resulted in a high degree of environmental destruction due to the large amounts of CO_2 being released (as well as nitrous oxides, sulfur oxides, and heavy metals). There is a strong correlation between economic decisions and the development of environmental challenges. This is clearly seen not only in Eastern and Central Europe, but throughout the world as a whole. "The existence of mankind has always been dependent on the natural environment...." [65].

According to Toth [65], as the forces of production develop, society takes possession of a greater and greater proportion of its natural environment. Interactions with the natural environment can be unbalanced and therefore negative if they are not developed appropriately. The first stage represents an interaction between nature and society that is weak and balanced. The preindustrial stage of development could be represented by such a formation. If industrialization occurs too quickly and without the proper direction, this interaction can become distorted and unbalanced within the geographical sphere of the environment. The extraneous spaces of this relationship are also influenced by this lack of balance. As industrialization gains balance and sound environmental direction, a stage three type formation can occur. This would be best described as a symbiotic relationship between society and the environment.

There is no doubt that once society and nature begin to interact, the interactions become more and more intense. If society so chooses, these intensities can result in strong mutual interactions that have balanced and strong positive mutual effects, as illustrated by stage three of the nature:society interaction, as postulated by Toth. Hungary has experienced a system of change from strong industrialization with qualitative production as a priority to a perspective of environmental remediation and sound policy. This shift is representative of the pursuit of the stage three formation.

A variety of climates exists in Hungary, including humid and arid zones. The presence of arid zones is of the utmost interest in the wake of global warming and the desertification processes, which are currently progressing at alarming rates. The Hungarian Great Plains are arid today due to the rapid population growth of the Eighteenth and Nineteenth Centuries. Accompanying the increased populous was a strong desire to cultivate the land. Eighty percent of the country's territory became suitable for agricultural purposes, and forest land decreased to compose only 11% of the land area. The Great Hungarian Plain became poorly watered and dry because of the rapid drainage of waters.

At the end of the Nineteenth Century, 80.9% of Hungary's total land area was used for agricultural purposes, and only 5.7% was considered land to be exempted from cultivation. By the middle of the Twentieth Century (ca. 1935), the agricultural sector comprised 81.4% of the total land area. At this time, 6.5% was considered to be exempted from cultivation. As of 1986 only 70.1% of Hungary's total land area was used for agricultural purposes and land considered to be exempted from cultivation had risen to 11.3%.

Cultivation of land requires the provision of adequate water resources. Hungary's total water resources average approximately 120 km^3 per year. Approximately 50% of this amount is due to direct precipitation. The majority

(94%) of the intracountry water supply within Hungary originates from the international water basin. This statistic obviously allows for a tremendous amount of control by other countries of Hungary's water supply, as well as adds a strong dimension of international relations to Hungary's water management staff. The international flavor of water resource management can be classically exemplified by the debate surrounding theGabcikovo-Bős-Nagymaros hydropower plant complex. In the context of this water issue, the construction of the river dam complex has been suspended due to ecological concerns relative to its existence. The intercountry negotiations on the technical details of its construction reached a deadlock. This issue is of such a magnitude that it is now being presided over by the international court in Hague. According to Halasi-Kun [25], this issue could be resolved in favor of Hungarian interests if a region upstream of the power plant along the Danube were simply averted to connect to connect at a point further downstream. This recommendation holds much promise for resolution of the Hungarian position within this debate.

If one were to analyze the resources that will be needed by the growing urban sector as well as the current (and increasing) industrial and agricultural sectors, one would see the obvious need to install a sound, comprehensive water resource program for the future. The future, according to Hock and Somlyódy [32], is bleak if control is not instituted. In their 1990 publication, they outline many factors that support the need to set realistic prices for water. To begin with, if one were to compare water use availability by months, there is an inverse relationship during some months. Due to the geographical nature of Hungary, the influence of water use by upstream countries will effect the quality and quantity of available water for Hungary.

The level of the Tisza is expected to decline in the future due to the construction of upstream reservoirs. These reservoirs are essential to the distribution of surface water supply. Sixty percent of the country's territory belongs to the drainage area of the Danube and eighty-nine percent of the water supplies run there. In comparison, 40% of the territory belongs to the drainage area of the Tisza, whereas only 11% of the water supplies are available there. The Tisza runs through the Great Plains, an area with tremendous historical agricultural output. However, this region is becoming more and more drought-susceptible and is increasing in semi-aridness on an annual basis. The anticipated drought years in the near future set the stage for increasing irrigation needs, if society (inclusive of agricultural output) is to continue in the future in the mode in which it has existed in the past. It is not believed that water will not be available in the next century, it is only necessary to implement a water management plan that provides for selected allocations.

Hungary has traditionally been an agricultural mecca. As a historical rule, Hungary has been a leading agricultural producer not only on a European scale, but on a worldwide scale as well. Agricultural practice requires a knowledge of how the land functions naturally (that is, without the presence of human intervention). This knowledge is needed to increase crop yields while simultaneously respecting the natural balance of the ecosystem. This type of knowledge might have been possessed over the past four decades, but was not significantly employed. The mechanization of agriculture, the formation of cooperative farming policy, and the increasing use of agricultural chemicals (pesticides, fertilizers, et cetera), are all examples of agricultural practices that were employed by Soviet policy in an attempt to increase crop yields to the highest possible levels. If the natural balance is not maintained, environmental quality will eventually deteriorate, giving rise to an even greater ecologically critical regions.

For a period of time, not much credence was given to the role agriculture played in causing a decrease in environmental quality in Hungary. Agriculture, however turned out to be a major source of pollution [23]. This sector has not only influenced the state of the environment, but reciprocally, agriculture has been influenced by the state of the environment. Today, nearly one-third of Hungary's arable land is endangered by either wind or water erosion. Due to a lack of sound agricultural practice over the past forty years, the soils also have inherent nutrient limitations. This (along with combating deforestation) will be two of the biggest challenge facing society well into the first decade of the next century. Of course, equally as large of a challenge faces the water managers in Hungary.

The research activities of the Hungarian water managers in semiarid areas are focusing on: 1) amelioration of arid soils by chemical and agrotechnical means; 2) drainage and irrigation improvements in semiarid areas; 3) the effect of "Lake Tisza" at Kisköre in the Hungarian Plains on the adjacent agricultural environment; 4) demand on water and regulation of soil moisture in connection with soil fertilization, chemical, and agrotechnical methods; 5) computerized models in measuring, analyzing, and predicting soil moisture and chemical data of soil for dynamic irrigation and chemical amelioration; 6) developing drought-sensitive plants and hybrids to decrease the water demand; 7) improving water management in larger semiarid areas by amelioration, protection, and development, as well as automatization of irrigation systems to improve crop fields [29].

ARIZONA FROM AN ENVIRONMENTAL PERSPECTIVE

Water demand is defined as the quantity of water required to sustain the activities of a society. Water supply is defined as the quantity of water which is available to meet the water demand. Water supplies in Arizona have historically been captured, stored, and transported to areas where demand has existed. Water demands are projected for each type of expected water use (agricultural, municipal, and industrial) based on population growth and economic trends.

Groundwater is a precious resource in Arizona, as it comprises over 60% of the State's water supply. As Arizona has met the challenges of development in a desert environment, groundwater has been pumped faster than it has been naturally replaced resulting in "overdraft". Overdraft in Arizona has resulted in increased costs of drilling and pumping, due to the fact that groundwater levels have declined as much as 183 meters in some areas [11]. Overdraft has also resulted in a decrease of water quality due to the increased concentrations of salts and minerals at greater depths. Of equal importance is the subsidence that has occurred due to groundwater overdraft. The "subsidence" is occurring in the earth's surface, thereby resulting in fissures. Within urbanized and industrialized areas, fissuring holds potential to damage roads, building foundations, and other underground facilities. Within rural regions, subsidence has occurred when agricultural irrigation has exceeded recharge.

Within the Sonoran Desert of Arizona, the sedimentary basins contain over 1,000 meters of unconsolidated clays, silts, sands, and gravels [28]. Before overdraft of the water table, most spaces between the soil and rock were filled with water. The lack of filled spaces has allowed sediments to become compacted due to the weight of the overlying material [28]. This scenario eventually leads to subsidence of the earth's surface.

Secondarily, earth fissures occur which are horizontal stresses developing due to stretching of the sediments. The sediments are various thicknesses (due to the different degrees of subsidence) [28], which further increase the instability of the system. According to Halasi-Kun, erosion can then widen these cracks until they increase to up to 10 meters wide and 10 meters deep, in addition to the potential to be 1,000's of meters long (Figure 1.27).

Water withdrawals are enormous not only in Arizona, but throughout the United States. Although approximately 1.5×10^{13} liters of water falls on the United States each day from precipitation, the majority of it disappears in the form of evaporation and runoff. Simultaneously, 1.28×10^{15} liters of ground- and surface-waters are being withdrawn in the United States each day. The U.S. uses three times as much water as the average European country, with an "allotment" of 4,918 liters $person^{-1}$ day^{-1} [24].

Presently, Arizona's water quality and quantity problems are occurring due to the rapid increase in the population growth of the state. Fortunately, concurrently with the population growth, there has also been an increase in water resources development. A main focus of water resource management in Arizona is placed on groundwater management, since it believed that the State's future development will depend on this supply. Arizona began to regulate groundwater withdrawals in 1980 by developing the Arizona Groundwater Management Code. Prior to passage of state legislation in 1980, the 1975 State Water Plan, published by the Arizona Water Commission (a predecessor to the Arizona Department of Water Resources) completed two phases of water analysis reports and began a third. The first phase report explained the occurrence of water in the State and its vital link to the people of Arizona. At that point in time, the Commission reported that the depletion of the groundwater aquifers of the State was severe and would be detrimental to its long-term economy.

The Second Phase report, entitled "Alternative Futures" (1977), reported that even with the importation of increasing surface water supply via the Central Arizona Project supplying water from the Colorado River, groundwater overdraft would continue at very high levels into the future. The Arizona Water Commission evaluated methods to improve water use efficiency in 1978 and published a third report to begin the Third Phase of the State Water Plan, entitled "Water Conservation". Once again, as in Hungary, water issues are tied very closely to economic development issues. In 1975, the long-term economy of the State was considered to be endangered by groundwater overdraft. The "Water Conservation" report was intended to provide recommendations for an improved water management program. However, this report was superseded by the passage of the 1980 Groundwater Act. This Act became the implementation plan to reduce groundwater overdraft through augmentation, as well as conservation.

Since the induction of the plan, many developments relative to water resource management have occurred. An additional two million people have moved to the State of Arizona; the surface water supply through the Central Arizona Project has been completed; the State is adjudicating the major watersheds in Arizona; Indian water settlements are being pursued; there are growing concerns about water quality and the preservation of riparian habitats; and the State has established comprehensive groundwater management programs in central Arizona (the main area of water demand) to eliminate overdraft.

Part of the solution to the problem overdraft is the Central Arizona Project (CAP). This federal reclamation project (overseen by the U.S. Bureau of Reclamation) has constructed this water-delivery system to transport Colorado

River water from Lake Havasu to central and southern Arizona (Figure 2.3). The CAP is projected to bring an annual average of 184,500 hectare-meters to cities, farms, and Indian tribes in the Maricopa, Pinal, and Pima Counties. Even though these three users have priority for CAP water resources, agriculture is charted to receive the surplus. The goal is to reduce the population's dependence on groundwater by providing a new surface water supply.

The system consists of three connected aqueducts, the Granite Reef, Salt-Gila, and Tucson (Figure 2.4), which convey water 539 kilometers across Arizona. A series of 14 pumping plants lift the water at intervals along the system to provide the elevation needed for gravitational flow. The first 27.3 kilometers of the aqueduct acts as a storage reservoir for the remainder of the system due to its larger construction. The water capacity of the aqueducts becomes increasingly smaller along the system as water is delivered to the schedules users. CAP water crosses three groundwater basins within the Lower Colorado River planning area before entering the management areas for which its use it targeted [18].

The second part of the solution to groundwater overdraft is the Arizona Groundwater Management Code, which arose from the 1980 Groundwater Act. The Code has three primary goals. The first is to control the severe overdraft currently occurring in many parts of the State. The second goal is to provide a means to allocate the State's limited groundwater resources to most effectively meet the changing needs of the State. The Code's third goal is to augment Arizona's groundwater through water supply development. To accomplish thesegoals, the Code established a comprehensive management framework and established the Arizona Department of Water Resources (ADWR). The ADWR has been directed (by the Code) to develop four Active Management Areas (AMA's) within the central and southern region of the state, where groundwater

Figure 2.3: Satellite Photo Map of Arizona

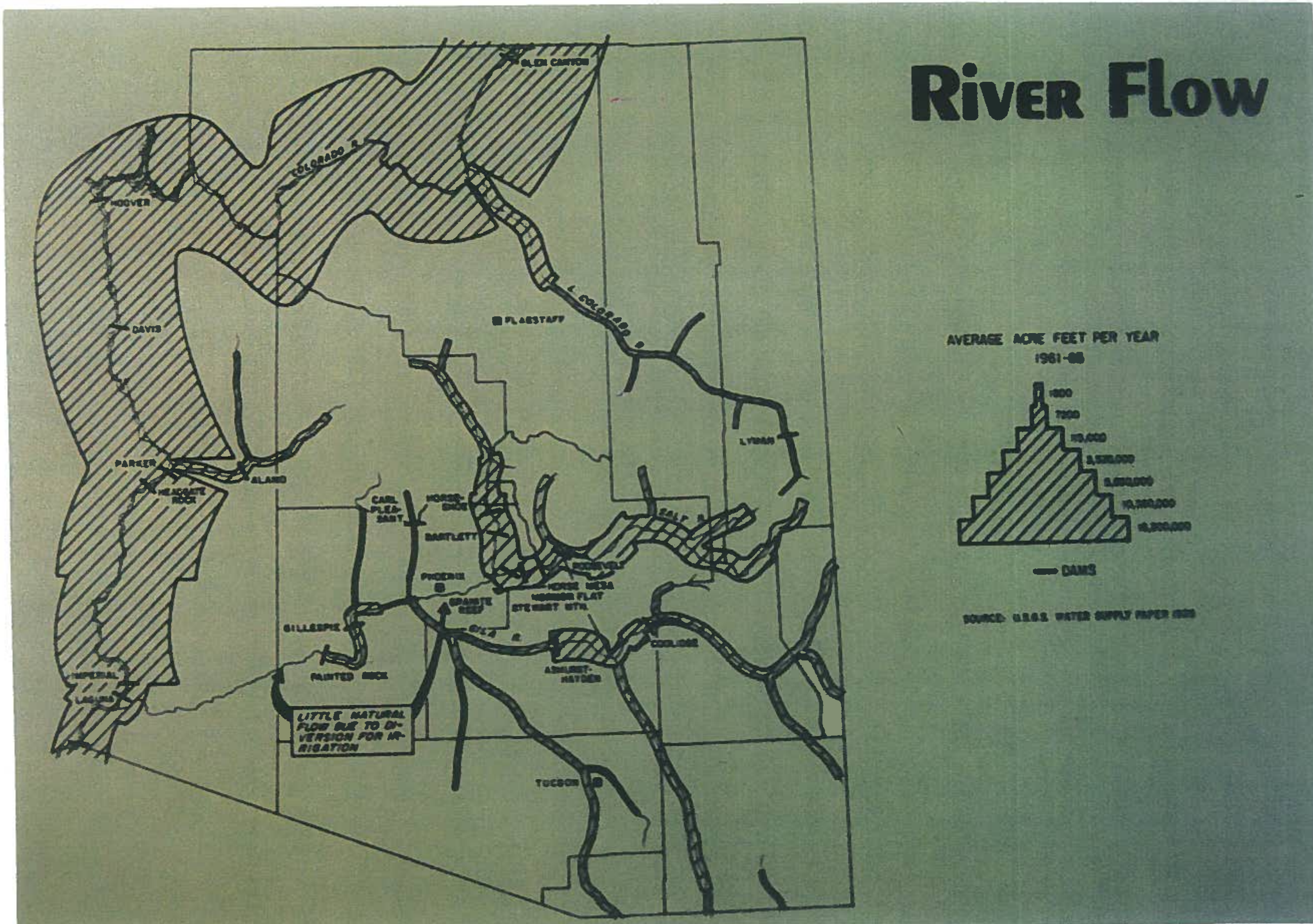


Figure 2.4: River Flow in Arizona

overdraft is most severe.

Although the surface water supplies of the Phoenix AMA serve as a source of groundwater recharge, only the Gila, Salt, Verde, and Agua Fria Rivers are used directly for water supply. The chemical quality of the water in these rivers generally is good. Reported values for total dissolved solids, sulfate, nitrate, and metals are all well within primary and secondary standards, with the exception of the Gila River. The Gila River is characterized by sulfate values of around 500 milligrams per liter (mg/1), twice the secondary maximum contaminant level of 250 mg/l. High sulfate levels in the Gila River may be caused by effluent discharged from the City of Phoenix wastewater treatment plants.

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CHAPTER 3:

POTENTIAL RAMIFICATIONS OF INCREASING DESERTIFICATION IN HUNGARY AND ARIZONA

INTRODUCTION

Threats to the global environment affect all nations despite their manifest diversity. The global environmental deterioration, especially global warming, will have profound impacts on the social and economic development of all countries of the world. Consequently, it is of the utmost importance to have an understanding of the impacts of climate change on man and his environment. Over the last century, the advancement of industrialized civilization has entailed disturbance to the earth's ecological balance. In reality, the climate issue is not only one of the most serious, but also one of the most complex global problems facing the world today. The increased emissions of greenhouse gases (particularly that of CO_2) has resulted in climate change and, of particular concern in Hungary and Arizona, furtherance of desertification.

Desertification, one of the most serious problems facing the world today, is characterized by degradation of soil and vegetative cover. There is potential for this process to occur in any area, not just on the fringes of natural deserts. Desertification is directly caused by four main types of poor land use: over-cultivation, overgrazing, deforestation, and poor irrigation practices. The increased aridification of climate has been thought of as being mainly catalytic, so that desertification accelerates as drought causes people to overfarm the land in an attempt to compensate for falling yields. The following assessments are hoped to have a significant influence on the development of sustainable responses by both

Hungary and Arizona as to the issue of increasing desertification.

Possible Outcomes of Increasing Desertification in Hungary

The land management practices of the previous Soviet government, and the legacy which these practices left to the present governments, have provided for large scale challenges in environmental matters. In conjunction with already compromised environmental conditions, the global changes in climate can be expected to further enhance the taxing of the Hungarian environment.

Decreasing water availability will further decrease the presence of riparian habitats. The ecological need for these habitats is fundamentally essential to the maintenance of an ecoregion. The ground cover, especially along riverbanks, provides for enhancement of soil texture and quality. Increases in global temperatures are expected to eliminate significant portions of riparian habitats during the progression of desertification. Hungary is as susceptible to this habitat loss as is any other region that will undergo desertification. Loss in vegetative cover enhances the desertification process, due to the loss of evaporation processes via the plant system.

Riparian fauna will also be lost during the progressive loss of the habitat as a whole. As species become endangered or extinct, there are reverberating effects on other ecoregions adjacent to the riparian habitat. As aquatic species decline in number, the food web experiences drastic, and even fatal changes. Loss of riparian habitats can even result in changes of migratory patterns and corridors of aves.

Overuse of groundwater supplies, a situation that typically exists in Hungary, will also prove to be a more deleterious event as water supplies are endangered by desertification. Nearly 75% of Hungary's total land area is under agricultural use. Regional climate impact studies indicate that global warming would create a compromising situation in agriculture and water resource management. This would be especially true if the increasing temperatures are continued to be accompanied by a substantial decrease in precipitation (Figures 3.1 and 3.2). It is to be expected that with increasing frequency and intensity of droughts, the entire agricultural structure will have to be adjusted. This will be a costly endeavor in terms of time and financial resources.

The Great Plain will initially experience the extreme ramifications of desertification. This is due to its characteristic dryness and higher temperatures. Additionally, decreases in precipitation during the desertification process will further influence the water supply of the Plain. This is due to the fact that the majority of groundwater of the Great Plains is believed to be derived from precipitation.

The upper 100 meters of the groundwater table of the Great Plain is considered to be fully contaminated [26]. One of the main contaminants is nitrate. Toxic levels of nitrate now exist in many subsurface waters due to overfertilization and agrochemical runoff. If water were to decrease via desertification, water quality will therefore be further compromised, as the dissolved solutes become more concentrated in the available water. Although children over three months and adults suffer no ill effects from ingestion of high nitrate, the major health hazard associated with this condition is infantile methemoglobinemia. This is a blood disorder that impedes the oxygen carrying capacity of hemoglobin.

Even though NO_3 accumulation occurs in surface waters via runoff, it is not considered a health hazard when found here due to its biological assimilation

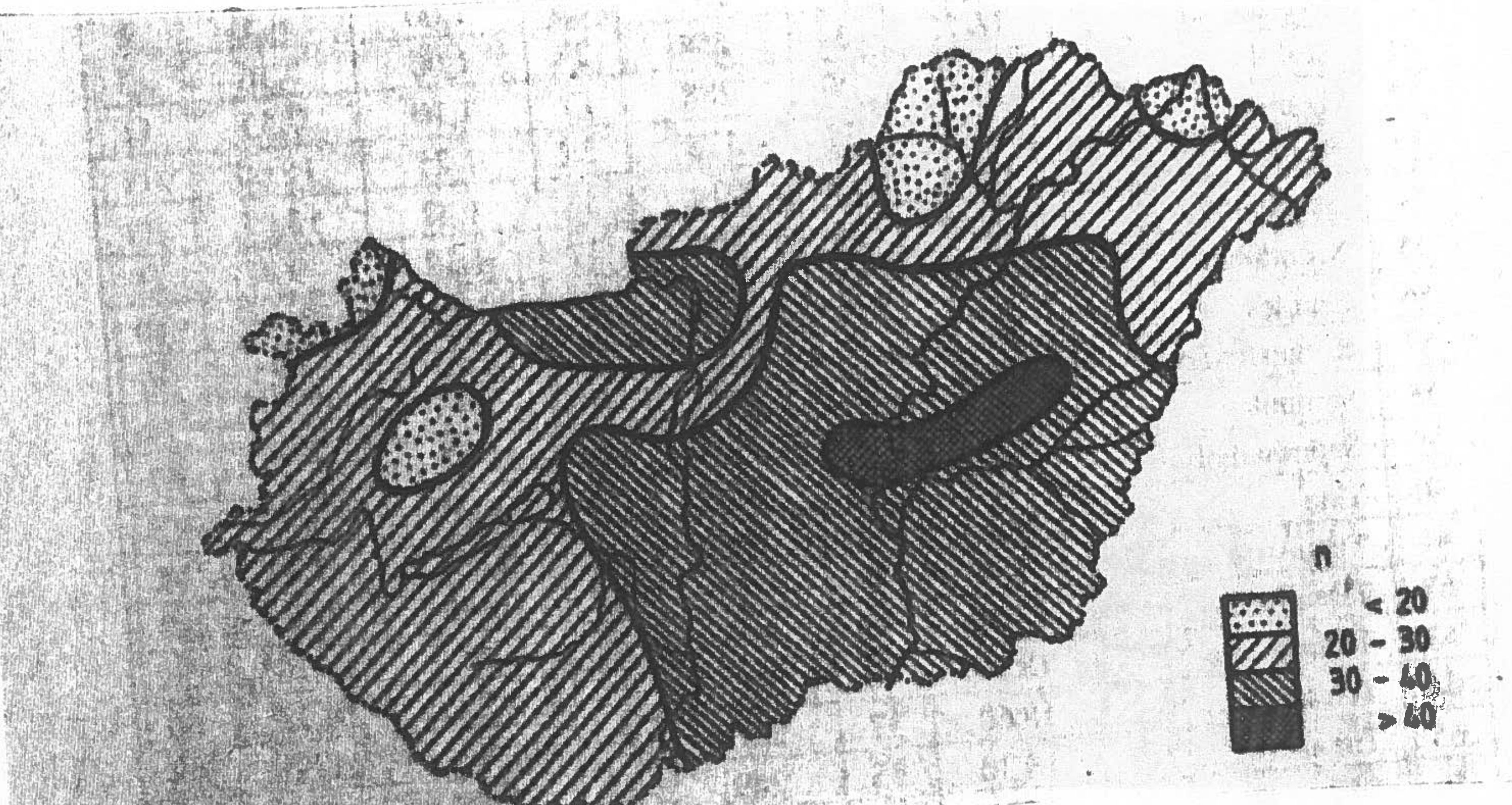

Figure 3.1: Areal Distribution of the "days of heat" in 1993

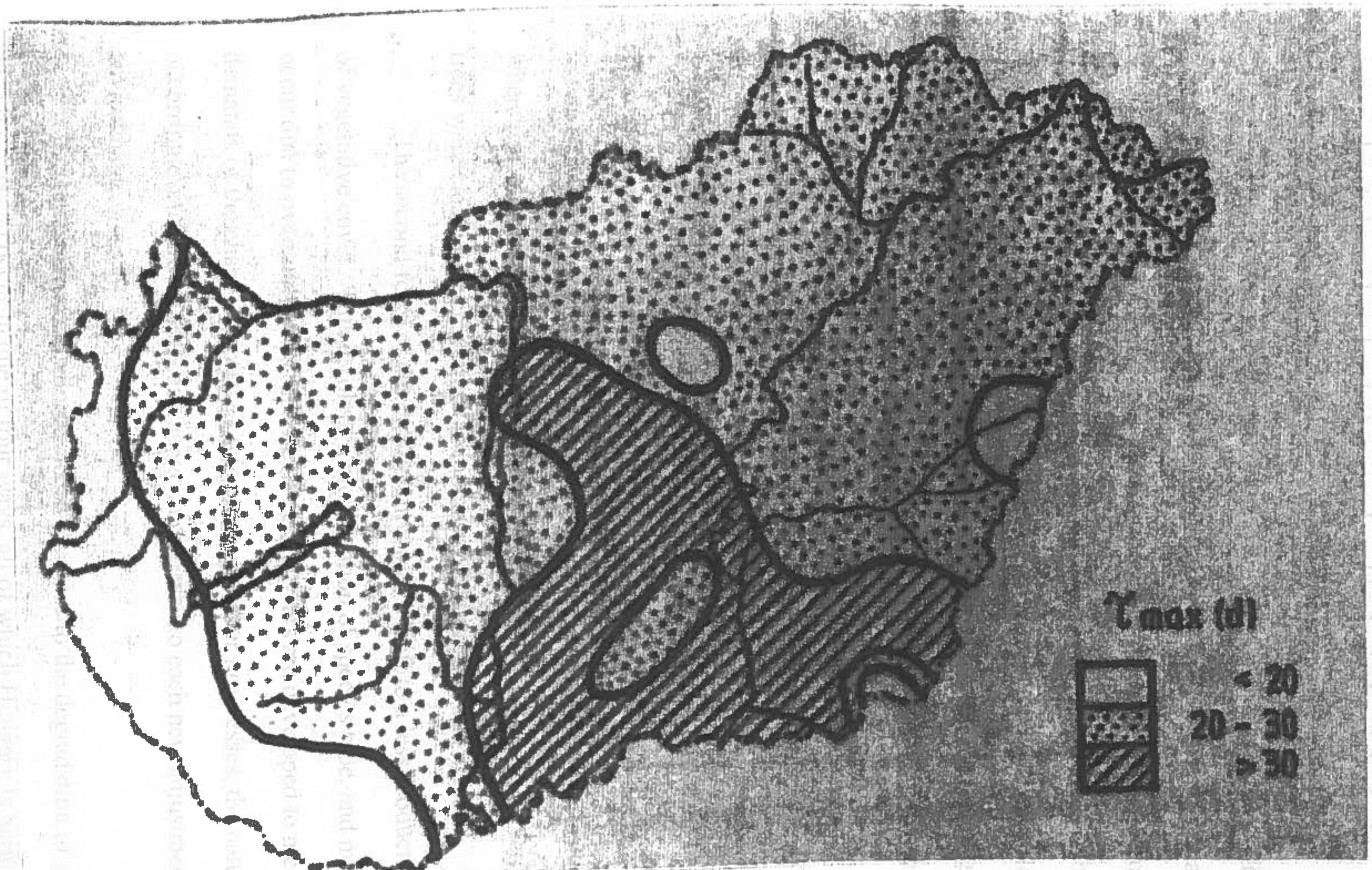

Figure 3.2: Areal Distribution of the longest precipitation-poor period of the summer of 1993

by aquatic plants and animals. In groundwater, however, NO_3 tends to accumulate to hazardous levels due to reduced biological activity in the hydrogeologic system.

The threat of desertification to the groundwater quality and quantity of the Great Plain is further exacerbated by the fact that the deeper subsurface layer of water is not being renewed. This is due mainly to the fact that a large proportion of subsurface water is fossil or static. Without the replenishing of the subsurface waters, only a minimal amount can be withdrawn before the water table level begins to significantly reach lower levels. If this were to occur, the Hungarian Great Plain could experience the occurrence of earth fissures that have occurred in Arizona due to groundwater overdraft.

One of the two main characteristics of desertification is the degradation of vegetation, which occurs early in the desertification process. It can be initiated by overcultivation, deforestation, or poor irrigation management. Degradation of vegetation occurs in two main forms. The first involves an overall reduction in the density of the vegetation. This is what occurred in the late Nineteenth century when agricultural production on the Great Plain became a paramount activity. As trees were cleared for cropping, the biomass of the region was reduced.

The second form of degradation involves a shift to a less productive type of vegetative cover. This involves a modification of species type, and may also occur due to overcultivation because newer cultivars are developed to meet the demands of the changing soil. As this process further progresses, the naturally-occurring events of the soil can change in response to each new adjustment to the environment.

Increasing desertification can also give rise to the degradation of soils. This process can occur in one of four ways, all of which Hungary is highly susceptible to. The first of these, water erosion can potentially endanger one-third of Hungary's arable land (2.3 million hectares) due to its susceptibility to this force. Normally, vegetation protects soil from being washed away by rains and by "splash erosion" (the direct impact of raindrops on soil). A more serious form of water erosion is "sheet erosion" in which the fine layers of topsoil are washed away. As this occurs, the soils of the Great Plain would suffer soil nutrient limitations. This could have a profound economic effect on the agricultural sector, and therefore on the country as a whole.

Wind erosion and soil compaction can also lead to soil degradation. According to Lóczy [45], 1.5 million hectares of Hungary's arable land is susceptible to wind erosion. This degradative process blows away finer soil components (usually containing the majority of the soil nutrients) leaving behind the less fertile sand and other coarser particles. These particles can be carried in dust storms damaging and sometimes killing crops by shredding foliage. The Great Plain could suffer ramifications of this process due to its decreasing amount of vegetation and the already -existing winds of the dry summers.

The high level of agricultural mechanization of the Twentieth Century has left Hungary's soils compacted. This event can further increase desertification of a region. Mechanical cultivation or cultivation during a dry season converts crumbs of soil particles into a thin powder, which, under the pressure of raindrops, is packed into a smooth, hard surface crust. Less water enters the soil for use by plant roots. This could also lead to a diminution of crop yields in Hungary.

Salinization, alkalization and waterlogging is the final process that can lead to soil degradation, and hence desertification. This process results from poor management of irrigated cropping and of water supplies in general. The irrigation of lands, without the proper attention to the quantity of needed irrigation can result in waterlogged soils. As excess water evaporates, the salts dissolved in the water are left behind. Saline and alkaline soils often occur in the same area, with the formation of one or the other depending upon the mineral composition of the soils and the state of the groundwater. As can be seen in Figure 3.3, actual and potential salt affected soils are very prevalent on the Great Plain. The potential for increasing salinity and alkalinity is especially large on the Great Plain. Soils of this status restrict the growth of plants. Eventually the land will become unproductive as "saline deserts" form.

If climate changes continue to occur on the Great Plains (as well as in other Hungarian macroregions), droughts will increase in frequency. Figure 3.4 illustrates the frequent occurrence of droughts particularly on the Great Plain. Climate (namely increasing global temperatures), acts as a catalyst to increase the rate of drought occurrence. Similarly, drought creates the conditions whereby human impact on land increases and the capacity of the land to tolerate the impact decreases. In the presence of drought conditions, crops and natural vegetation grow poorly, forcing people to crop the land more intensively in an attempt to compensate for falling yields. This in turn depletes soil fertility and organic matter, and reduces the land's protective vegetative cover, already depleted by the effects of the drought on soil moisture. The results are increased soil and vegetation, the two indicators of increasing desertification.

Hungary, therefore, will experience many ramifications of global warming and desertification. If measures are not taken to soon limit the negative anthropogenic influences on the environment, not only will the environment and human health suffer, but so will the further economic development of the region.

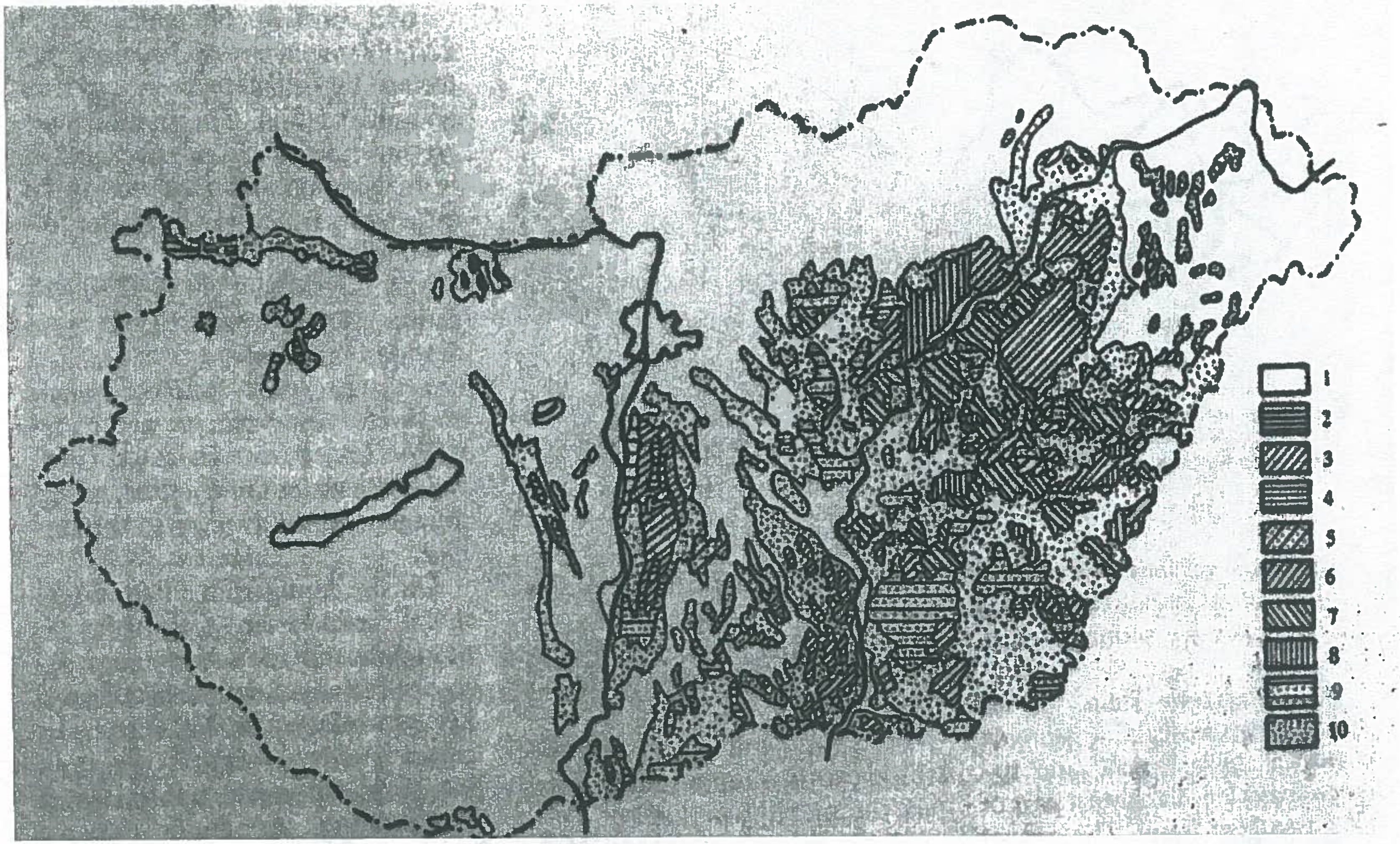

Figure 3.3: Actual and Potential Salt Effected Soils in Hungary

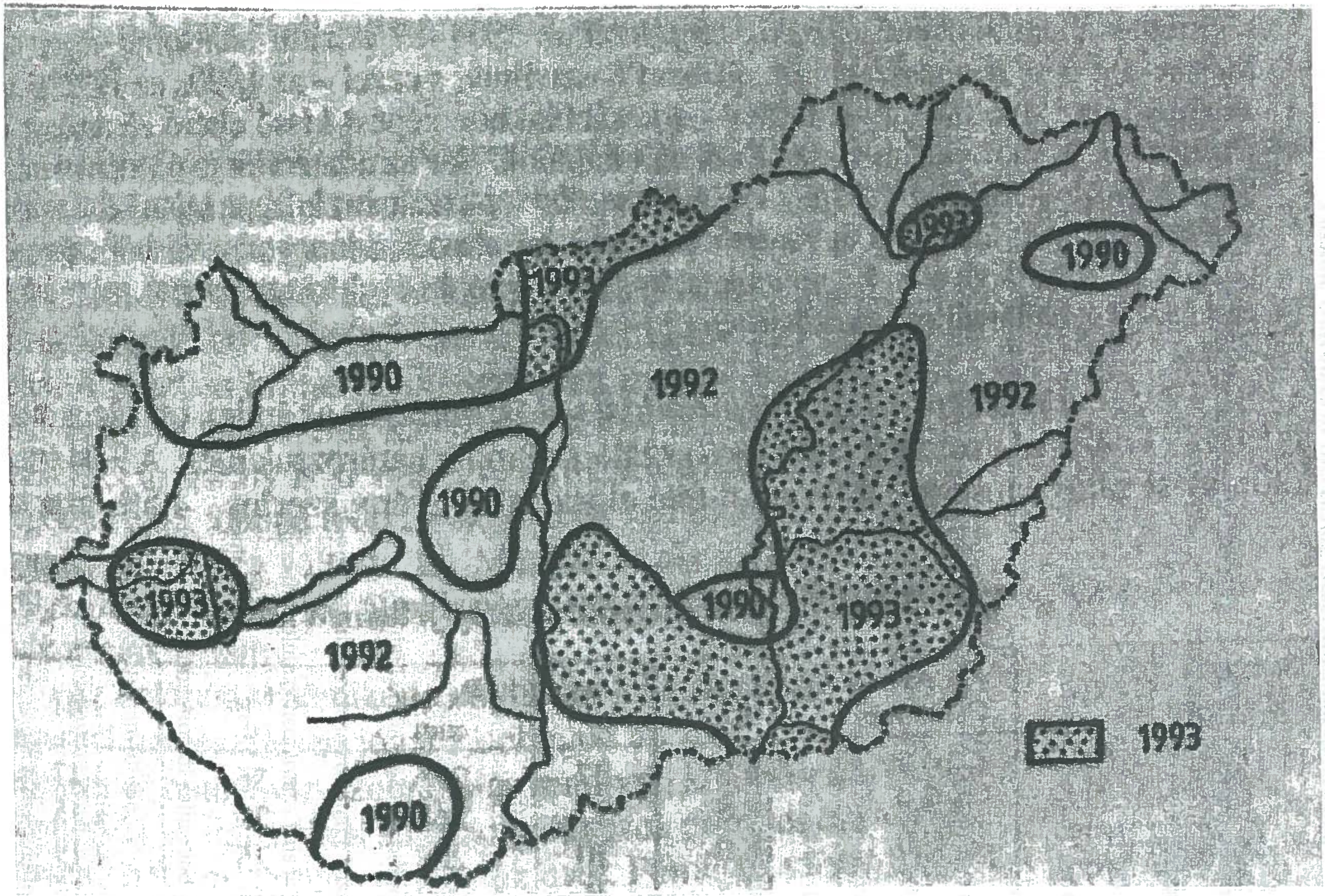

Figure 3.4: Areal Position of the Largest Droughts of 1990-93

Possible Outcomes of Increasing Desertification in Arizona

The riparian habitats in Arizona have been decreasing at an alarming rate since the early 1980's. Numerous aquatic plants are presently on the endangered or extinct species list. The desert seems to be ever-encroaching on an annual basis. Formal preservation now exists for many riparian habitats in the form of protected land. However, climate knows not to follow the invisible boundaries established by the human habitat managers. Since desertification occurs due to interacting forces: human intervention and climatic changes, at least one of these influences can be controlled. The natural influence of increasing temperatures can be controlled as well, however, only over time will noticeable results occur. In the meantime, Arizona will likely continue to experience a further decrease in her riparian habitats.

Arizona has traditionally used low quality irrigation water which results in the development of saline-alkali conditions. This situation is not unlike that of Hungary's. Overirrigation has resulted in increased water logging of the soils, thereby following the above-described process of evaporation and increased solute concentration. Additionally, various Arizona soils of the Basin and Range Province have high concentrations of sodium and soluble salts. This condition results from the concentration of run-off water into the enclosed drainage basin where the water evaporates and leaves behind the solute concentrate. This is directly attributed to poor management techniques.

Groundwater overdraft has also increased the formation of saline and alkali soils. The cones of depression that have formed in many of the hydrogeologic units within the Basin and Range Province have resulted in waterlogging of the local soils. Arizona can expect increasing soil degradation, and hence desertification in light of various improper water management techniques.

Arizona soils can be further degraded by wind erosion of the silt and clay components of the hydrogeologic units of the sub-basins. The flora of the region tend to be adapted to the soil particles that hit them during dust storms, however, the erosion process is still occurring. This, as in the Great Plain, will assist in enhancing the desertification process.

One of Arizona's most challenging consequences of global warming will be in providing adequate water supplies. Groundwater is no longer depended upon to the degree it once was. The decreasing quality and quantity of this source has forced reliance upon surface waters. However, increasing desertification places additional pressures upon the already very limited supply. The citizens of Arizona are going to have to face high prices for water in the future. The commodity of this natural resource will exponentially increase as temperatures increase and precipitation decreases in the environment.

Additionally, the maintenance of artificial environments for comfort of the human population will be a challenge for Arizona in the wake of increasing global changes. Presently, Arizona is highly challenged on 47°C days (which are no longer uncommon during the dry, hot summer) when air conditioning units cannot function. Society in the desert, as it is presently established, cannot function without the augmentation of air conditioning. This is partially due to the architectural design of the buildings.

The temperature cycle of the Basin and Range Province is not as predictable as it was once. High temperatures are arriving earlier in the summer and staying later in the fall than ever before. However, the pattern or occurrence of these temperature differences cannot be predicted. Arizona is also experiencing higher temperatures on a year to year basis. As global warming accelerates, the Basin and Range Province will be particularly susceptible to such increases. Due to its geographical location, much of the heat tends to become "trapped" in the mountain-surrounded basin area. Soil fertility of the A horizon could potentially decrease as temperatures increase. There is an inverse relationship between soil organic matter and temperature. This will eventually decrease the biomass of the vegetation, thereby furthering the desertification process.

CHAPTER 4:
AGRICULTURE AND THE ENVIRONMENT IN HUNGARY AND ARIZONA

HUNGARY AND AGRICULTURE

Hungary has traditionally been an agricultural mecca. As a historical rule, Hungary has been a leading agricultural producer not only on a European scale, but on a worldwide scale as well. Agricultural practice requires a knowledge of how the land functions naturally (that is, without the presence of human intervention). This knowledge is needed to increase crop yields while simultaneously respecting the natural balance of the ecosystem. This type of knowledge might have been possessed over the past four decades, but was not significantly employed. The mechanization of agriculture, the formation of cooperative farming policy, and the increased use of agricultural chemicals (pesticides, fertilizers, et cetera), are all examples of agricultural practices that were employed by Soviet policy in an attempt to increase crop yields to the highest possible levels. If the natural balance is not maintained, environmental quality will eventually deteriorate, giving rise to ecologically critical regions.

repeated

For a period of time, not much credence was given to the role agriculture played in causing a decrease in environmental quality in Hungary. Agriculture, however turned out to be a major source of pollution. Nearly three-quarters of Hungary's land area is suitable for agricultural production. The percentage of land presently under intensive cultivation registers the highest in Europe. As indicated in Table 4.1, Hungary's arable land comprises 50% of her total land

	thousands of hectares	%	thousands of hectares	%	thousands of hectares	%
Arable land	5,103	55.5	5,601	60.3	4,705	50.6
Gardens	95	1.0	114	1.2	339	3.6
Orchards	--	--	--	--	99	1.0
Vineyards	175	1.9	207	2.2	147	1.6
Meadows and pastures	2,067	22.5	1,644	17.7	1,234	13.3
Agricultural land	7,440	80.9	7,566	81.4	6,524	70.1
Forests	1,249	12.9	1,099	11.8	1,659	17.8
Reeds and fish ponds	48	0.5	32	0.3	66	0.7
Productive land	8,737	94.3	8,697	93.5	8,249	88.6
Land exempted from cultivation	528	5.7	603	6.5	1,054	11.3
Total land area	9,265	100.0	9,300	100.0	9,303	100.0

Table 4.1: Land Under Cultivation by Area

area. To maintain modernization standards within the agricultural business sector, heavy farm equipment use has increased from 6% in 1935 to 100% in 1980 and chemical fertilizer use has increased almost ten fold since 1960 (Table 4.2). The increase in mechanization has resulted in not only soil compaction, but also in deterioration of soil water retention capacity.

If there were to be a decrease in water quality or quantity, Hungarian agriculture would be adversely effected, not only in regards to presently employed agricultural practices involving water, but (of equal importance) in regards to what could potentially be beneficially introduced in the future. Percentages of lands presently being irrigated is only a fraction of what could be irrigated (Table 4.3). Approximately 25% of Hungary's agricultural land lies in areas affected by drought. Water loss (whether it be quality or quantity loss) in the future will obviously effect the potential for increasing agricultural irrigation applied with a moisture regime control.

As with many Hungarian sectors, agricultural is too, in a state of transition. Water supply to Hungarian agricultural lands is vital to their functioning. This is especially true within the Great Plains region where potential farming is great due to the tremendous land area, but where evaporation is greatly exceeding precipitation, giving rise to a substantial annual drought index (Figure 4. 1).

Agriculture is not the main water use sector, according to the National Central Office (Figure 4.2). It comprised approximately 13% of the total water use in the national economy between 1970-1984. This amount is not static, but varies from year to year, depending on the amount needed for irrigation, which is the largest water consumption aspect within the agricultural sector. According to the Central Office for Statistics, irrigation and aquaculture account for 76% of the

	1960	1970	1975	1980	1986
Supply of fertilizers in active agents (1000s of tons)	167.5	837.1	1,518.3	1,399.1	1,383.3
of which: nitrogen	74.5	391.2	535.8	536.8	593.4
phosphorous	66.0	217.0	429.4	390.2	355.0
potash	27.0	229.0	553.1	472.1	434.9
Fertilizer per hectare agricultural land (in kg)	23	122	224	211	212
Fertilizer per hectare of arable land, garden, orchard and vineyard (in kg)	--	150	276	262	262

Table 4.2: Supply of Fertilizers

	Total irrigated land (1000s of ha)	Rice	Arable land	Meadow and other	Gardens
		Percent			
1950	33	46	23	15	16
1970	109	21	41	17	21
1975	156	17	55	22	6
1980	134	11	41	29	19
1986	163	7	66	23	4

Table 4.3: Irrigation by Type of Land

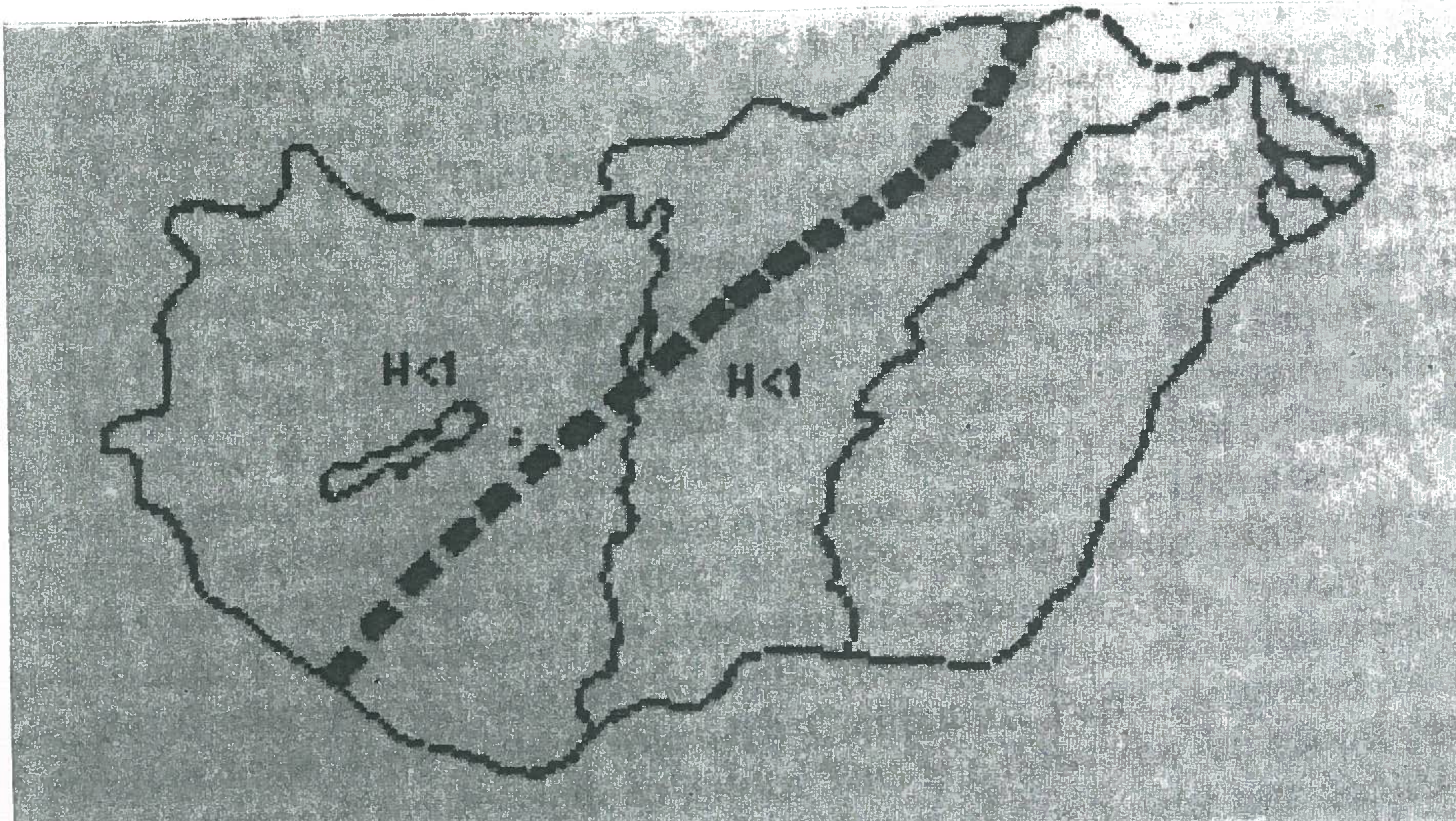

Figure 4.1: Drought Index: H = Evaporation per year/Precipitation per year

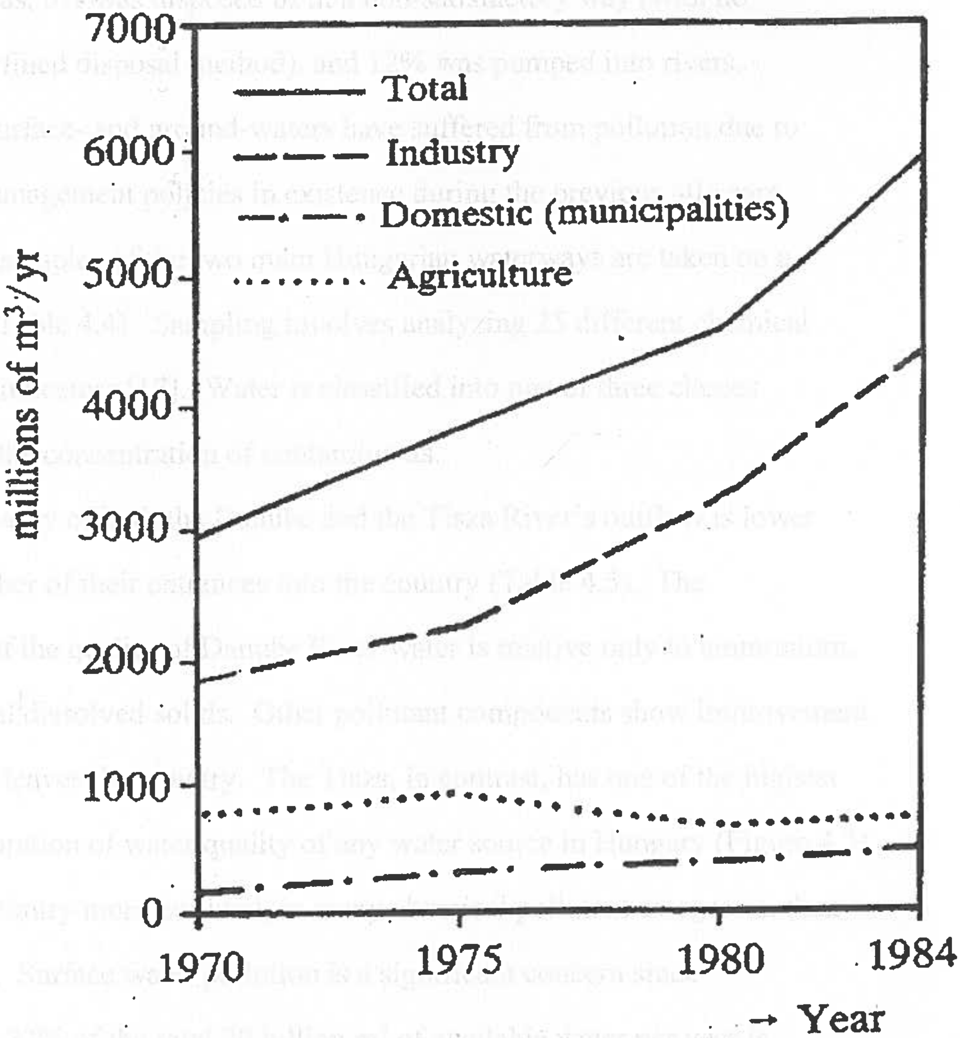

Figure 4.2: Water Use According to Sector

water used in agriculture in a normal growing season [32].

Agriculture has also contributed to water pollution. Large-scale farming operations produce liquid manure at a rate of 48 million m^3 $year^{-1}$. Of this total volume produced, 42% was spread on fields as fertilizer, 40% was discharged into designated areas, 6% was disposed of in a non-satisfactory way (with no particularly defined disposal method), and 12% was pumped into rivers.

Both surface- and ground-waters have suffered from pollution due to agricultural management policies in existence during the previous 40 years. Surface water samples of the two main Hungarian waterways are taken on a regular basis (Table 4.4). Sampling involves analyzing 25 different chemical water quality indicators [17]. Water is classified into one of three classes depending on the concentration of contaminants.

The quality of both the Danube and the Tisza River's outflow is lower than it is at either of their entrances into the country (Table 4.5). The deterioration of the quality of Danube River water is relative only to ammonium, nitrate and total dissolved solids. Other pollutant components show improvement as the Danube leaves the country. The Tisza, in contrast, has one of the highest rates of deterioration of water quality of any water source in Hungary (Figure 4.3). It leaves the country more polluted, in many chemical pollutant categories, than when it enters. Surface water pollution is a significant concern since approximately 33% of the total 20 billion m^3 of available water per year is contained within surface water. According to the Central Office for Statistics, annual water use amounts to approximately 20% of the total resources available (Table 4.6).

Groundwater resources are mainly comprised of bank-filtered water stored along the banks of the Danube and the Tisza in alluvial formations. These

River system	*Sampling frequency*			*Total*
	52 (weekly)	*24 - 26 (bi-weekly) (sample/year)*	*11 - 12 (monthly)*	
Danube	16	99	54	169
Tisza	23	52	6	81
Total	39	151	60	250

Table 4.4: Sampling Sites of Surface Water Grouped According to River System and Sampling Frequency

Stream	Nitrate ion mg/l					Orthophosphate ion mg/l				
	IV		V		VI	IV		V		VI
Kapos	4.9	→	6.4	→	7.1	1.19	→	1.60	→	3.24
Zala	5.8	→	6.8	→	8.4	0.50	→	0.74	→	1.07
Zagyva	13.1	→	14.9	→	15.1	0.86	→	1.00	→	15.1
Danube (entrance)	17.1	→	8.6	→	9.5	0.59	→	0.62	→	0.58
	↓		↓		↓	↓		↓		↓
Danube (outflow)	6.9	→	8.7	→	8.8	0.39	→	0.47	→	0.44
Tisza (entrance)	2.7	→	4.0	→	5.2	0.13	→	0.15	→	0.08
	↓		↓		↓	↓		↓		↓
Tisza (outflow)	6.2	→	8.1	→	12.1	0.14	→	0.26	→	0.25

Table 4.5: Mean Values of Nitrate and Orthophosphate Ions During the Fourth, Fifth, and Sixth Five-year Plan Periods (1976-80, 1981-85, 1986-90)

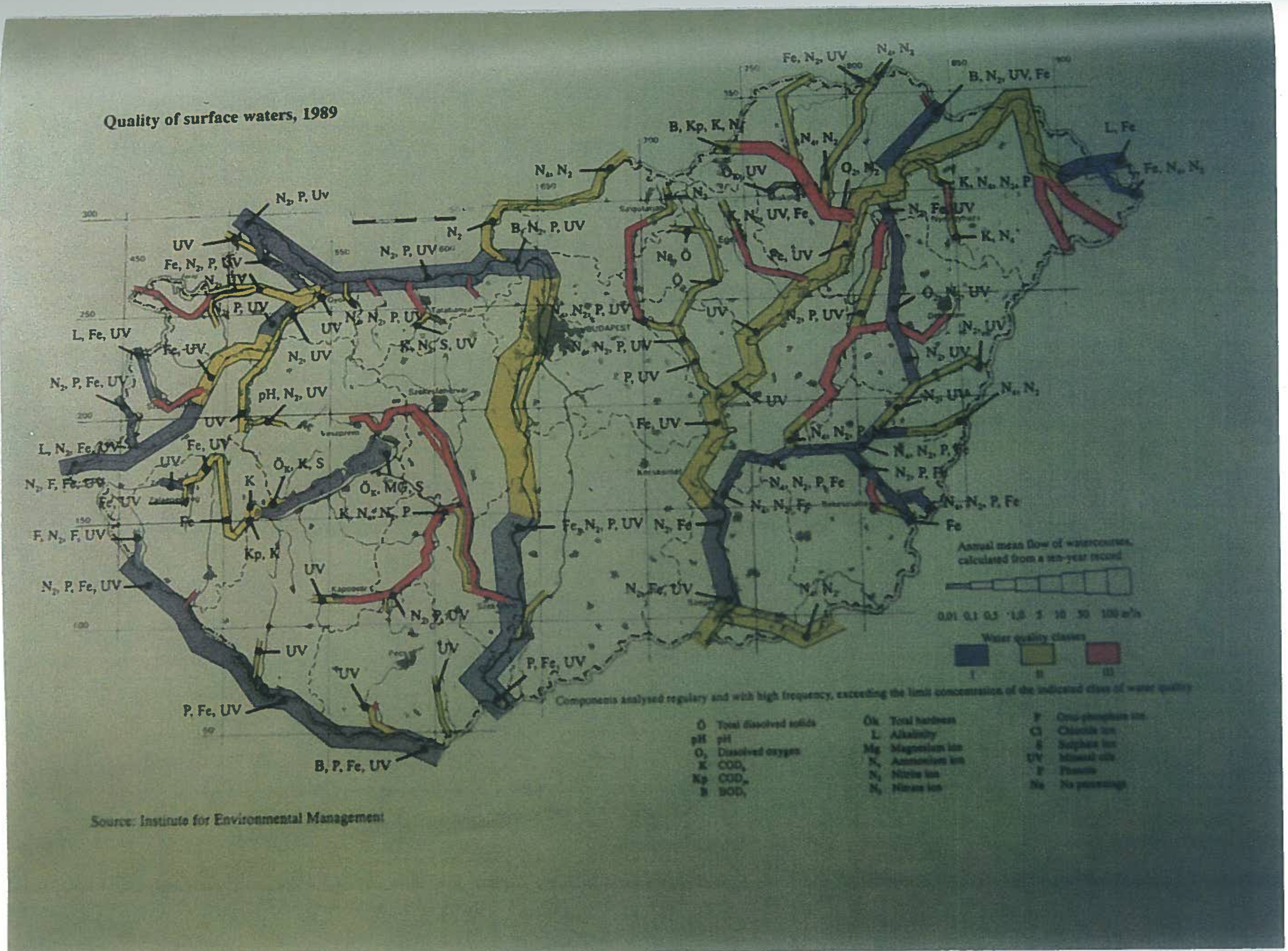

Figure 4.3: Quality of Surface Waters

	Water use (millions of m³/yr.)	Uncommitted resources available (millions of m³/yr.)	Total (millions of m³/yr.)
Surface water	2,788	10,481	13,269
Groundwater	1,095	5,409	6,504
Total	3,883	15,890	19,773

Table 4.6: Total Water Availability and Use

are followed in prevalence by artesian wells, unconfined groundwater, and lastly karstic waters.

Hungary also has a great supply of geothermal waters (419 million m^3 year $^{-1}$), however 33% of these are warmer than 60° C. Groundwater quality data for those waters lying between 50 and 600 meters in depth is shown in Figure 4.4. The classifications of water quality are relative to the amount of treatment needed. Since Budapest alone withdraws approximately 312 million m^3 of bank-filtered water each year for municipal use, the quality of such groundwater is exceptionally important. The bank-filtered water of the Danube has progressively lost its quality index, thereby decreasing the quality of the regional well water.

Heavy metal concentrations (particularly iron and zinc) are higher in the sediments of the Danube than are the maximum limits that are set for soils growing food crops [32]. If one were to analyze groundwater on Csepl Island just north of Budapest, one could find highly polluting results. For each of the 4 components considered, NO_3, organic carbon, iron, and manganese, the groundwater has been found to be highly polluted. Nitrate contamination is, once again, of serious concern. The standard concentration of allowable nitrate in drinking water is 20 mg/l. Tolerable levels should not exceed 40 mg/l. The majority of this island is experiencing NO_3 levels of this concentration; 5% of the area has NO_3 levels of 200 mg/l.

Of the 3,000 towns and cities in Hungary, approximately 700 (containing 300,000 inhabitants) rely on water to be trucked or piped in from neighboring communities due to nitrate contamination of the local water supplies.

Other groundwaters are beginning, for the first time, to become polluted by surface infiltration. The Great Plains of Hungary not only has increased salt content in the groundwater, but is projected to increase in the concentration of

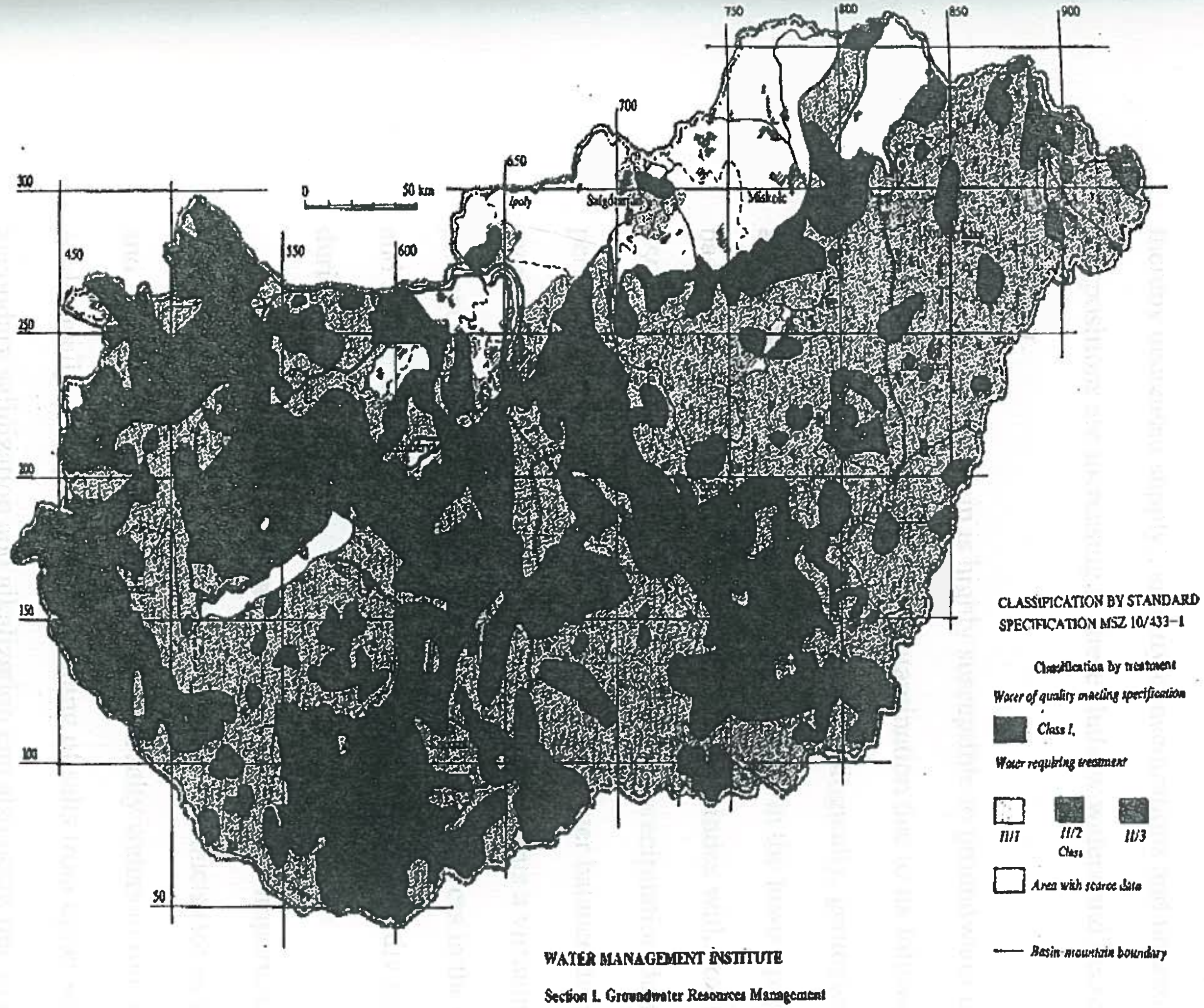

Figure 4.4: Groundwater Quality in Various Hungarian Hydrogeological Areas

other contaminants. Even though the Great Plains has traditionally had a high agricultural output, various factors are presently potentially hazardous to the level of this output. Groundwater overdraft is one of these factors and demands immediate attention. In addition to the decreasing depth of groundwater (and thereby decreased supply), salinity concentrations and unfavorable ion compositions are increasing in these shallow waters and decreasing the quality of the water.

The Great Plain is highly susceptible to groundwater contamination (particularly by salts) and soil contamination due to its following characteristics: it is by all standards (hydrologically, geologically, geomorphologically, and hydrogeologically) in the lowest part of the Carpathian basin; it experiences a sizable annual drought index with potential evaporation of 650 - 700 mm $year^{-1}$ and only 500 - 550 mm precipitation during the same time period; there is a considerable deficit in the water balance during the dry summer months (-70 - 80 mm $month^{-1}$); the basin represents a virtually closed system; the presence of thick, salty Tertiary and Quarternary layers in the geological profiles; and stagnant, salty groundwater has the potential to rapidly rise to the surface during rainy periods.

The Puszta groundwaters represent the most important sources of salt because they accumulate soluble weathering products (for example, sodium salts), and then act as transport vehicles to push salty waters to root zones of crops. Additionally, they prohibit the leaching of salts from upper soil horizons. Secondary salinization and alkalization can also occur due to improper irrigation techniques (or other factors in irrigation practice that are controllable), not poor water quality [67]. For example, leach-drain technology has been the method of choice on the Plain, however, this technique does not control salinity. Unlined irrigation canals deteriorate the quality of water directly from these canals. Seepage from unlined canals and water reservoirs, in addition to filtration losses from irrigated fields causes the water table to rise, delivering additional saline groundwaters to the surface.

It is hypothesized that increased agricultural activities will involve expanded use of fertilizer and pesticides in the future. If this is true, the quality of Hungary's surface- and ground-waters will deteriorate even further. Nitrogenous fertilizers (in comparison to other fertilizers) most easily lose their active ingredients, penetrate beyond root zones, and do not break down easily. These characteristics make them the primary causative agents of increasing ground- (and surface-) water contamination.

A second type of agricultural chemical that is over-employed are the pesticides (inclusive of herbicides, fungicides, and insecticides). Pesticide use has increased by statistically significant percentages since 1965. These chemicals cause environmental stress by altering the balance of biotic interactions. They tend to produce a cidal effect on beneficial organisms, as well as on pathogens.

Agriculture has been found to have a significant impact on the present state of the Hungarian environment. Obviously, the recently used protocols for agricultural production does not provide for the agricultural sector's contribution to a sustainable plan for the future environmental state.

AGRICULTURE AND ARIZONA

When reviewing the interactions with agriculture and water quality and quantity issues in Arizona, one must differentiate between Indian water use and non-Indian water use. Indian Reservations are not subject to government regulations (on either the federal or state level), including those established by the Groundwater Code. Unless otherwise stated, all water-use issues in this manuscript will pertain to non-Indian water use.

The Active Management Areas (AMA's) are now in their Second Management Plan, however, during the First Management Plan (which was published in December 1984), the Arizona Department of Water Resources (ADWR) issued 6,978 certificates of irrigation Grand fathered Rights for farm units larger than two acres within the Phoenix AMA. These were issued primarily on the East and West Salt River Valley, Rainbow Valley, and Hassayampa sub-basins. The certificates permitted the irrigation of 157,545 hectares. By December of 1987, the total number of certificates issued had increased to 7,334 due to numerous conveyances and transfer rights to new owners, which sometimes split an original farm into two or more smaller farms. The total number of active certificates capable of being irrigated has decreased to 6,844 (which is equivalent to 140,706 hectares[1]).

The average farm size in the AMA is 20.66 hectares, and ranges from two acres to over 3,108 hectares. Based on yearly reports of measured agricultural

[1]: This area reduction is due mainly to the high level of urbanization within the central region in the Phoenix AMA. Urbanization has caused numerous irrigation Grand fathered rights to become inactive or transferred to non-irrigation rights.

water use, total use in 1984 was 153,069 hectare-meters; in 1985, 152,150 hectare-meters; and in 1986, 124,664 hectare-meters. Average water use represents 62% of the total 230,533 hectare-meters allotted annually by the First Management Plan for the active irrigation grand fathered rights.

The reduction in agricultural water use that occurred from 1984-86 was principally due to a reduction in cropped acreage. Reduction in cropped acreage was mainly the result of federal acreage limitation incentive programs and comparatively low crop prices. The total number of irrigation acres is the maximum number of acres which may be irrigated in any year, however, the ADWR projects than an average of only 75% of these acres will be irrigated in any year.

In 1980, approximately 68% of irrigation waters came from groundwater. Surface water from the Salt and Agua Fria Rivers comprise the remaining 32% of irrigation water use. These two rivers were delivered by various irrigation districts. Several farms in the Buckeye Irrigation District did use surface water that was created by the discharge of treated municipal effluent to the Salt River. By 1986, 52% of irrigation water was groundwater and 48% was surface water. The increase in use of surface water for agricultural irrigation purposes is primarily attributed to the delivery of the Central Arizona Project (CAP) water (as well as higher than normal Salt and Agua Fria River levels).

By 1990, approximately 90% of all irrigation water in the Phoenix AMA was being delivered by fourteen large irrigation districts, which deliver both groundwater and surface water (including CAP). The irrigation districts involve 5,925 farms and service to 111,111 hectares of crops. A constant source of water in 100% of these districts is well water; a source susceptible to contamination. The main source, according to Plan, of supply to these districts is CAP water, which is supplemented by groundwater. However, approximately 10% of the farms within the AMA are not served by either an irrigation district or an irrigation delivery district. These farms rely exclusively on groundwater. The pumping of groundwater is not energetically inexpensive. Most irrigation wells use electrical power as the principal source of energy for pumping, however some irrigation wells (in outlying areas) are powered by natural gas, diesel fuel, or propane gas.

The primary crops grown within the AMA, which are under irrigation, are cotton (51%), wheat and barley[1] (22%), alfalfa (12%) and orchard crops (15%). These crops have been constant since 1975.

Irrigation systems within the Phoenix AMA vary between field crops. The majority of the systems involve flood irrigation with water delivered to the fields in concrete-lined ditches. In 1986, a survey found that 61% of the Phoenix cropland was irrigated with slope systems without tailwater reuse facilities, 24% was irrigated with slope systems with tailwater reuse facilities, 11% was irrigated with level basin systems, and 4% were irrigated with nonflood systems, such as sprinkler or trickle systems.

Agricultural irrigation has been most benefitted by the laser-leveling technique. This technique, employed since the mid-1970's, involves leveling a conventionally sloped field to a flat or nearly flat grade with greatly improved precision. The increase in precision comes from the use of a laser-beam to the cuts and fills made by the earth scraper during the leveling operation. This technique has improved irrigation efficiency from 50 - 65% before leveling to 75-90% after leveling. On some cotton fields, this increase in efficiency has resulted

[1]: These cereal crops are commonly rotated with cotton.

in an annual water use savings of over 0.308 hectare-meters hectare $^{-1}$.

Groundwater use for agricultural purposes has decreased to 35% from the 50% of the First Management Plan. It is also expected that as the 1990's continue, water costs for most farms are expected to increase as depths to water continue to increase and energy costs increase. As construction and operation costs for CAP are transferred to irrigation districts, water costs for farms will, in turn, also increase. Urbanization is also expected to increase, transferring agricultural water use issues to, municipal (and possibly industrial) water use issues.

Agriculture remains a predominant source of contamination in streams, largely because it is the principal land use (in terms of area) in Arizona. Historic over-utilization of rangeland and agriculture clearing practices have resulted in the removal or loss of protective vegetation from valley bottoms and desert rangelands. This has significantly contributed to accelerated erosion and high turbidity. Agricultural practices have also been a source of boron, nutrients, nitrate and sulfate, pesticides, and Total Dissolved Solids (TDS) contamination.

High turbidity (in conjunction with suspended solids and siltation) remains the principal cause of stream impairment and a major cause of lake impairment. Turbidity is defined as the cloudiness of water due to suspended solids and organic matter. Turbidity standards were established in Arizona to protect Aquatic and Wildlife and Full Body Contact uses; however, high turbidity may indicate impairment of other uses. Generally, high turbidity is a symptom of accelerated erosion associated with bank de-stabilization, channel cutting, topsoil removal, and contamination transport. Surface water may also become so muddy that it is unfit for livestock consumption. Streams in arid regions are expected to have higher turbidity due to sparse vegetation and erodible soils, however, anthropogenic activities (particularly those of agriculture) appear to have accentuated this turbidity.

Boron contamination in sensitive crops is a result of poor irrigation practices. Discharges from the wastewater treatment plants (or from some discharge of natural sources) may contribute to high levels of boron to the surface water. The source of boron in wastewater may be boric acid that is widely used to control cockroaches (Order Blattodea) in municipal water systems. The use of this wastewater or sludge for crop irrigation may introduce high levels of boron to agriculture lands. Evapotranspiration concentrates boron, and the use of boron-laden irrigation waters is toxic to sensitive crops.

In Arizona, very few lakes are not man-made. Most of the lakes are shallow impoundments which significantly increase in temperature in the summer, thereby accelerating natural eutrophication. Noxious aquatic plants and high pH levels are common. Fish die offs are less common, but occur where extra nutrients have been added to the system. This has particularly been a problem at lakes using wastewater effluent. Agricultural runoff has additionally contributed to this problem due to the conjunctive use of fertilizers and wastewater effluent for irrigation. This combination in agricultural practice has also resulted in nitrate and sulfate contamination of ground waters.

Pesticide contamination occurs near landfills and agricultural areas in Mesa [6], as well as in many other areas of the Phoenix AMA. The pesticides most commonly found are ethylene dibromide (EDB) and the organochlorine pesticides. The use of DDT has been banned in Arizona since 1969 and the use of toxaphene was banned in 1982 due to their persistence and ability to bioaccumulate. The presence of organochlorines is due to over spray of agricultural fields, rather than direct application. Soil samples from Painted Rocks Lake study area, southwest of Phoenix has indicated extensive residual pesticide contamination (Table 4.7).

Another pesticide study was conducted in the central Phoenix area by the Arizona Department of Environmental Quality (ADEQ) in 1992 due to the occurrence of a childhood leukemia cluster. The area of concern had been previously in agricultural fields. In soil samples collected around ten sites, DDT metabolites, toxaphene, heptachlor, and aldrin were detected at levels higher than the Health Based Guidance Level. Ziram, a fungicide and seed treatment, was also detected, but no guidance level has been established.

Total Dissolved Solids (TDS) have become a leading cause of contamination in lakes and streams as a result of changes in assessment guidance by the Environmental Protection Agency (EPA). It is characteristic of Arizona's surface waters to have naturally high levels of TDS, however a review of the monitoring data reveals noticeably higher TDS levels downstream of some irrigation canal return flows. The United States Geological Survey (USGS) has indicated that agriculture is the largest anthropogenic source of dissolved solids in (primarily) the Upper Colorado River Basin. Irrigation increases salinity by consuming water and by dissolving salts found in the underlying saline soils and geologic formations. Deep percolation mobilizes the silts found naturally in the soils, especially if the lands are over-irrigated.

Routine surface water monitoring is conducted by the ADEQ and the USGS for the following toxicants: pesticides, metals (including arsenic), ammonia, chlorine, other inorganics (including selenium), and organics. The

PESTICIDE	RANGE IN SOIL* (mg/kg)	HBGL* (mg/kg)	RANGE IN STREAM SEDIMENTS* (mg/kg)
DDT METABOLITES	0.07-5.13	4.0	<detection level-0.44
TOXAPHENE	<detection level-18.0	1.2	<detection level
TOTAL PESTICIDES	0.38-23.86	--	--

Table 4.7: Stream Sediment Samples Collected by the U.S. Fish and Wildlife in 1985-87 (HBGL = Health Based Guidance Level)

extent that these toxicants are known to cause surface water pollution in Arizona is summarized in Table 4.7. There are other stressors which could be considered toxic to man, plants, and other animals that were not included in these statistics (for example, radiochemicals and pH). According to the reported statistics, 29% of the state's surface waters are considered to exceed toxic standards. Additionally, 42% of the area of the state's lakes exceed toxic standards.

CHAPTER 5:
URBANIZATION AND THE ENVIRONMENT
IN
HUNGARY AND ARIZONA

HUNGARY AND URBANIZATION

During the previous 40 years, "economic development and urbanization have transformed Hungary's natural environment into one characterized by heavy industrialization, the growth of urban centers, the large scale mechanization of agricultural production and the expansion of the transport and energy sectors" [71]. Urbanization brings with itself newly formed municipal settings with increased population demands. In 1987, Hungary reported a rate of 114 people per km^2, ranking 14th on the population density scale amongst European countries. The distribution of the population is not even, as can be seen in Table 5.1. Urbanization is continuing to increase, with 20% of the population living in Budapest. Industrialization is a main cause of this population distribution. Not only does urbanization concentrate people, it therefore also concentrates pollution, especially if living conditions are not as developed and advanced as they could be. Hungary's housing units increased from 2.4 million units in 1949 to 3.9 million units by 1987. Ten percent of these housing stocks were built in the last century, and 25% were built during the first half of this century. As indicated in Table 5.2, basic utility supply to residential dwellings has been on a statistically significant increase since 1949. As of 1987, 99% of all flats in Hungary have electricity, 85% have piped water, 75% have a bathroom, and 66% have a toilet or lavatory. However as

	1949	1960	1970	1980	1987
Urban population	36.8	39.7	46.4	53.2	58.9
of which: budapest	16.3	18.1	19.4	19.2	19.7
Rural population	63.2	60.3	53.6	46.8	41.1
Total	100.0	100.0	100.0	100.0	100.0

Table 5.1: Urban and Rural Population (in percent)

One room	70.5	62.7	46.1	27.5	19.2
Two rooms	24.6	32.6	43.2	48.6	48.2
Three or more rooms	4.9	4.7	10.7	24.0	32.6
Dwellings with:					
Piped water	17.0	22.7	35.1	62.7	77.7
Sewerage	—	—	36.8	65.4	78.9
Lavatory	12.6	16.1	26.4	51.4	67.2
Bathroom	10.1	17.0	30.8	58.5	73.7
Piped gas	7.0	10.6	16.0	25.1	30.5
Inhabitants per 100 dwellings	373	360	331	302	273
Number of rooms per dwelling	1.4	1.5	1.6	2.0	2.2
Inhabitants per 100 rooms	265	245	202	152	124

Table 5.2: Housing Stock by Numbers of Rooms and Services (in percent)

in Figure 5.1, only approximately 27% of Hungarian dwellings are piped to public sewers. Even more hazardous is that, of this 27%, only one-half of the waste reaches a sewerage treatment plant, the other one-half is released, untreated, into surface waters.

Approximately 20 million m^3 $year^{-1}$ - of municipal solid wastes are produced in Hungary. Of this amount, about three-fourths are incinerated and placed in landfills, however there is a critical shortage of suitable landfills in Hungary [64]. Of particular concern to Hungarian water resource managers, is the 7 million m^3 of municipal solid waste collected in Hungary each year. As already stated, the majority of municipal sewerage effluents are discharged hazardously into surface waters. Sewerage treatment plants have been upgraded to handle the increased burden of municipal waste. However, of the approximately 2,600 waste dumps in operation, 900 are completely unsupervised (35%) and only 100 of them are even attempting to be in compliance with environmental regulatory policies (3.8%) [64].

Urban development increases the demand for goods and passenger transport. The economic growth experienced by increased industrial and manufacturing enterprises (inclusive of suburban manufacturers), the evolution of suburbs, and the increased desire for leisure time (especially that involving transportation to summer houses, et cetera) has resulted in a statistically significant increase in demand for transportation (of both passenger and freight nature). Between 1950 and 1970 passenger kilometers in the public transportation sector grew three and one-half times and the tons of freight transported grew four times. Between 1950 and 1986 there was a one hundred fifty-fold increase in the number of passenger cars on Hungary's roads.

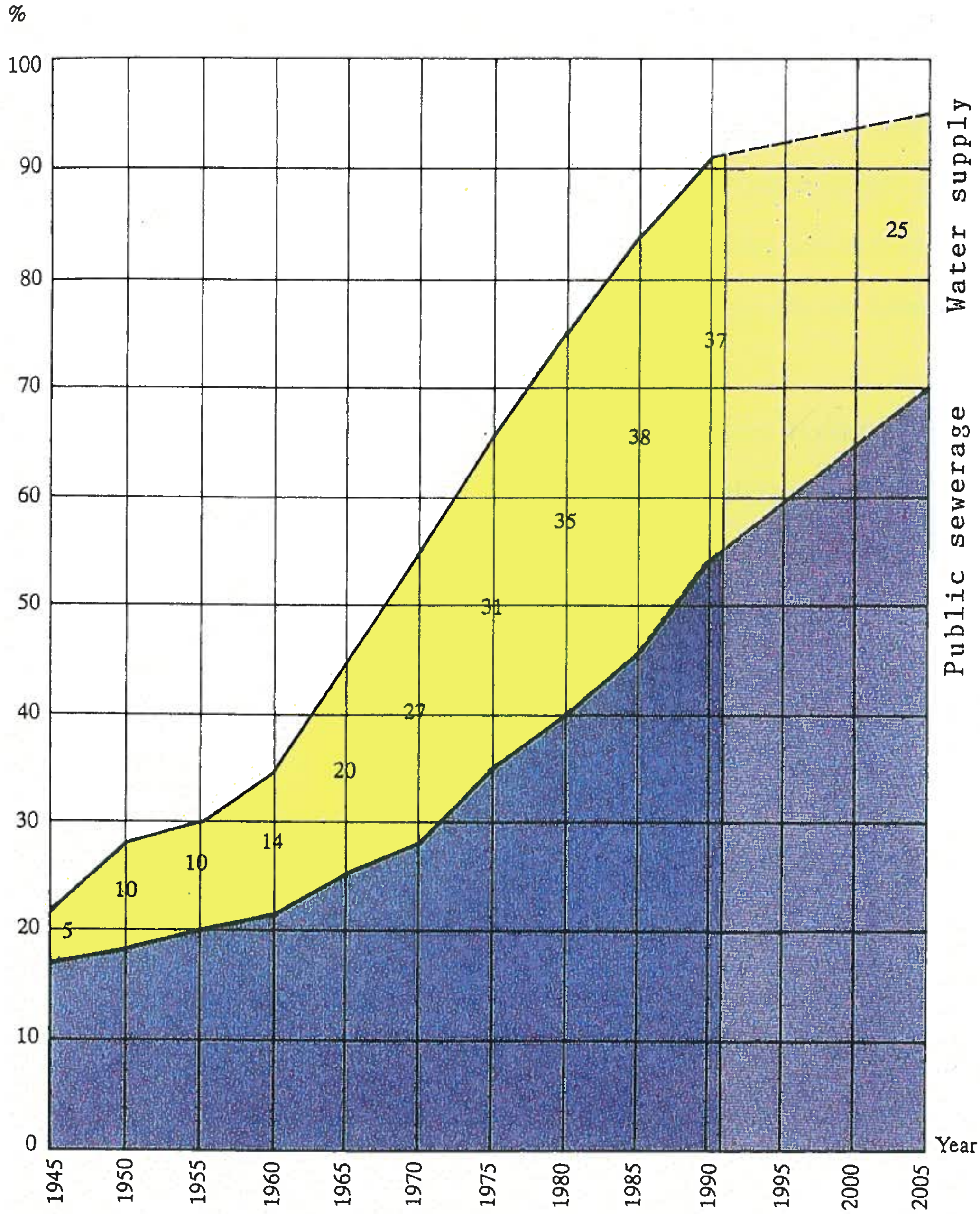

Figure 5.1: Quotient of Inhabitants with Public Water Supply and those with Public Sewerage

Of the present passenger car road fleet, 42% of the cars are older than 10 years, 20% are 7-9 years old, 18% are 4-6 years old, and only 19% are 3 years old or newer. Enhancing the problem of older cars, one-third of the Hungarian passenger fleet consists of cars containing two-stroke engines--a mechanical design notorious for increasing emission release due to elevated hydrocarbon release. The number of buses has increased approximately threefold since 1955, with 60% of them operating on diesel (which produce considerable amounts of nitrogen oxides), while the remaining 40% burn petrol (which is responsible for carbon monoxide, hydrocarbon, and lead emissions). The average age of buses in operation is good; less than 8% are more than 10 years old.

Each year Hungary's road vehicle fleet produces: 1million tons of carbon monoxide; 130,000 tons of hydrocarbons (of the polycyclic form, which are known carcinogens), 120,000 tons of nitrogen oxides; 36,000 tons of solid particulates; and 510 tons of lead and lead-related compounds.

Sulfur pollution is also a major concern in Hungary. Hungarian mined lignites have high sulfur concentrations and are polluting the environment via power plants and domestic furnaces (which have been identified as a main polluter). Nitrous and nitrogen oxides are also produced from this source (as well as from industrial activities).

In addition to the direct integration to human health of the pollutants (inhalation and heavy metal uptake by edible plants, thereby entering the food chain), acid deposition in some areas of Hungary is increased, and anthropogenic activities of a municipal nature are thought to be accountable by some sources. According to Várkonyi and Kiss [68], recent acidification of large areas of Europe can be attributed to vehicular emissions of acid-forming precursors. Even though acid-rain is not considered to be a significantly higher problem in Hungary than in the rest of Europe, that comparison is not a realistic one due to increased acid deposition throughout Europe and an increased concern for the effects of acid rain in numerous European countries. The air pollution monitoring network (Központi Légkörfizikai Intézet) collects data on both the acidity of rainfall as well as the amount of dry acid deposition. The average pH distribution of precipitation for Hungary is 4.67. The Great Plains are not that much higher, with a pH registration of 4.95. The frequency of the distribution of precipitation in terms of pH is concentrated at 72% between pH 4-6. Sulfuric and nitric acid are responsible for the acidity of rainfall at a ratio of 3:1. Of particular concern, terms of ground water quality, is the fact that NO_3 concentrations in Hungary's rainfall increased 4% year $^{-1}$ between 1979 and 1989. In addition to the costs of acid deposition by damages to health and buildings, agriculture and water supplies are also endangered.

Soil acidification has been increasing since 1977. The main hypotheses for the decrease in pH are summarized in Table 5.3. Fifty-five percent of these causes are of anthropogenic origin, and 9% is thought to be directly correlated to urban/municipal development.

Main Reasons		Consequences	Possibilities for Control
Natural Factors	Human Activities		
- acid (non calcareous) parent material - root respiration - decomposition of plant residues (CO_2 acidic substances) - leaching (as a result of permanent or dominant downward flow (high precipitation + low water retention) - natural acidic depositions	- change in land-use practice - change in agrotechnics - improper fertilizer application (form, dosage) - amelioration (acidic amendments, drainage) - industrial and urban wastes and sewage waters - wet and dry acidic deposition (air pollution due to industrial and urgan development)	- decrease of pH - decrease of barbonate content - decrease of buffer- - capacity - more intensive weathering - leaching and/or immobilization of plant nutrients - biological degradation - unbalanced fertility status of the soils - limited nutrient uptake by plants - lower fertilizer-use efficiency - mobilization of toxic elements	- rational (adequate) fertilization system dosage; Ca-fertilizers) - chemical amelioration (liming; use of alkaline substances) - air-pollution control

Table 5.3: Soil Degradation Processes: Acidification

ARIZONA AND MUNICIPAL WATER DEMAND

The Phoenix Active Management Area (AMA) includes the most populated and largest urban area in Arizona (Figure 5.2). From 1980-1985 the populous grew from 1,511,000 to 1,850,393 inhabitants. The Department of Economic Security (DES) projects for the year 2025 an estimated population of 5,335,649 people (Table 5.4). This will obviously give rise to an increased water demand. When comparing municipal water use in 1990 with projected municipal water use in 2025, one will find an increase of 27.2% municipal demand, and a 33.4% decrease in non-Indian agriculture water use demand, a logical trend in scope of increased urban development.

Municipal water demand includes all water provided by cities, towns, private water companies and irrigation districts serving non-irrigation users. The two primary variables influencing municipal water demand are per capita water consumption and population. Urban irrigation demand includes untreated deliveries of water for non-irrigation uses within a municipal service area, generally for watering of landscapes and small pastures. These waters are delivered through a different system (and usually different provider) than are treated waters.

In 1985, there were two major sources of municipal water in the AMA: groundwater and Salt River Project (SRP) delivery. SRP water is primarily from the Salt and Verde Rivers, but is augmented with ground-water from approximately 250 wells. Municipal water treatment plants receive SRP water according to allotments for lands within city boundaries that are "on project" (in other words, within the SRP service area). Eight large providers

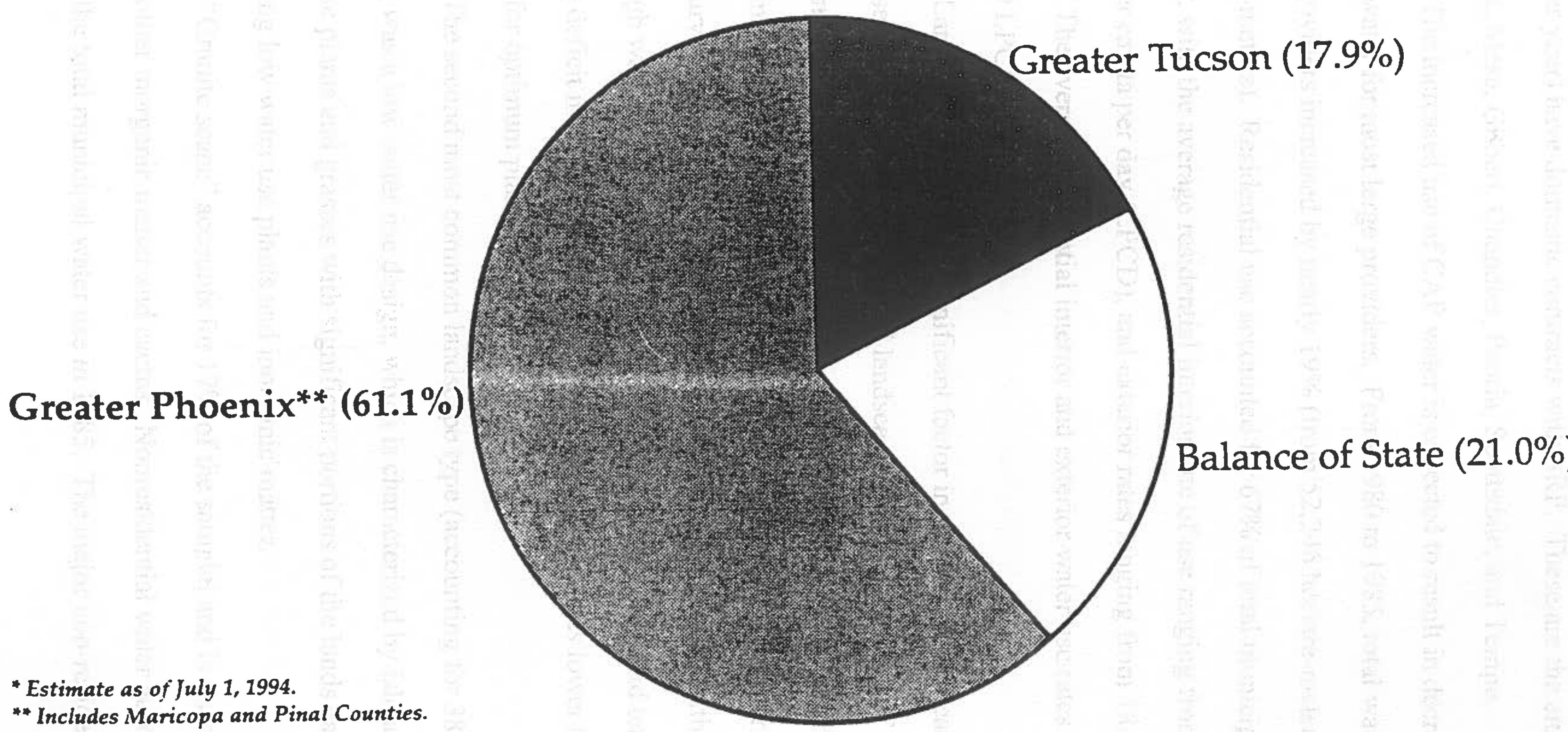

Figure 5.2: Arizona Population Distribution, 1994

(those that serve 500 or more people or supply 1.3 hectare-meters of water or more per year) have domestic contracts with SRP. These are the cities of Phoenix, Mesa, Gilbert, Chandler, Peoria, Scottsdale, and Tempe.

The increased use of CAP water is expected to result in decreased use of groundwater for most large providers. From 1980 to 1985, total water use by large providers increased by nearly 19% (from 52,246 hectare-meters to 61,054 hectare-meters). Residential use accounted for 67% of total municipal water use in 1985, with the average residential interior rate of use ranging from 189 to 597 liters per capita per day (LPCD), and exterior rates ranging from 18.9 to 1,701 LPCD. The average residential interior and exterior water use rates were 30.2 and 279 LPCD, respectively.

Landscape design is a significant factor in understanding residential water use. To determine residential landscaping trends, a survey of approximately 2,200 single family homes (3-8 years in age) was conducted. The survey included homes on lots of 1/6, 1/4, 1/3 and 1/2 acre or larger. The results of the survey indicated that 45% of the homes were landscaped with lawns and other high water use vegetation. Nine percent of these homes did tend to practice deficit irrigation, meaning that they irrigated at rates lower than was needed for optimum plant health.

The second most common landscape type (accounting for 38% of the sample) was a low water use design, which is characterized by islands of high water use plants and grasses with significant portions of the lands capable of containing low water use plants and inorganic matter.

"Granite scape" accounts for 17% of the sample, and is characterized by rock or other inorganic matter and cactus. Nonresidential water accounted for 33% of the total municipal water use in 1985. The major non-residential water users include: 1) Turf - related facilities (golf courses, parks and schools); 2) Construction companies; 3) High-technology industries; 4) Hospitals; 5) Retail and service businesses; and 6) Office buildings. Effluent use within a municipal service area is not included in the water use rates reported above. The use of effluent has been increased since 1980, totalling approximately 9,594 hectare-meters in 1986. This represents approximately 40% of the effluent produced in the Phoenix AMA. Effluent use has most recently been employed in the watering of golf courses and the in the maintanence of artificial lakes within residential areas.

The Phoenix AMA currently has 78 small providers, each carrying with itself intrinsically unique characteristics. Small providers are classified as such based on the fact that they serve less than 500 people or deliver less than 12.3 hectare-meters. An example of a small provider would be a mobile home park. Due to the individualistic characteristics of each small provider (for example, the population served by small providers ranges from less than 10 people to more than 500), water use patterns of theses providers vary considerably.

Groundwater is the primary water source for the small providers. Eight (10%) of the small providers do hold contracts for CAP water allotments totaling 2,471 hectare-meters. However, only two (2.5%) of the water companies have assured water supply designations based on hydrological studies of current groundwater resources.

The Arizona Department of Water Resources has defined municipal untreated water providers as those delivering untreated water for non-irrigation uses through a distribution system separate and distinct from that used to deliver treated water. Untreated waters are used for irrigation (agricultural) and non-irrigation purposes. The most common non-irrigation use is the watering of lawns and small pastures. All municipal untreated water providers are private water companies (inclusive of actual small companies as well as homeowners associations and institutions). One hundred percent of these providers pump groundwater from their own wells, providing 274 hectare-meters in 1985. Expansion of this municipal water use sector is not expected to increase in the near future due to difficulty in geographical expansion (most are surrounded by the mainstream treated water providers), and the rising costs of pumping groundwater.

There are also seventeen agricultural untreated water providers delivering both ground- and surface-waters to non-irrigation users. This sector provides the majority of the untreated water for urban purposes within Phoenix. In 1985, they transported and delivered approximately 15,621 hectare-meters of water, and this may be higher than reported due to the fact that deliveries are difficult to accurately measure. The proportion of these deliveries could potentially increase as larger percentages of lands are developed.

Since sewerage treatment is highly regulated in Arizona, the release of raw sewerage from municipal settings into open surface waters is not a large-scale risk. Many rivers and streams outside of the urban setting are susceptible to endemic waterborne diseases. These can be directly attributed to human recreational activities in the area. Effluent from septic tanks may contaminate groundwater with bacteria and nitrate. The 1980 census estimated that approximately 280,000 septic tank systems are operating in Arizona, serving nearly 17% of the state's population. Nitrate levels in groundwater have been decreasing in some areas where urbanization has replaced agricultural activities, but have increased where septic tanks are a primary wastewater disposal system.

Municipal point sources are significant sources of pollutants based on state compliance records. Between October 1991 and September 1993, 41% of the point source permit holders did not meet the discharge limitations of their permits, therefore contributing to impairment of surface waters. However, there was almost no in-stream monitoring during the past five years above and below these point sources to confirm the impacts of these discharges.

CHAPTER 6:

INDUSTRIALIZATION IN HUNGARY AND ARIZONA

INDUSTRIALIZATION IN HUNGARY

The pollution of Hungarian waters increased steadily from the beginning of the industrialization period of the second half of the 19th Century in Budapest until the 1950's, at which time forced industry took place from 1950-60. During this period, industrial output grew 10% $year^{-1}$, after several transitions, it is presently growing at 1-2% $year^{-1}$. Table 6.1 shows a representation of the index of Gross Production of Industrial Sectors from 1955 to 1986. Heavy industry (which includes mining, metallurgy, electric energy, engineering, chemical and building materials) not only generates the largest economic benefit, but also generates the most pollution. The regional scope of pollution increased to towns and environs of Budapest due to new industrial development in the areas of heavy mechanization, mining, and chemical industries [59] industrial by-products have directly polluting effects on Hungarian farm water supplies, or have undergone some various environmental reaction to produce a new pollutant product, such as the presence of acid rains from sulfur and nitrogen oxide production.

The chemical industry has created heavy metal pollution exceeding acceptable levels for metals such as mercury in highly populated areas such as Budapest [59]. Domestic pollution arising from limited sewerage remediation measures have created low quality stagnant waters that can be positively detected by bacteriological investigations. Anthropogenic sources of pollution have not remained concentrated coming from specific and large sites, but have

	1955	1960	1970	1980	1986
Mining	165	201	314	357	356
Electric energy industry	178	277	627	1,206	1,422
Metallurgy	199	273	463	638	654
Engineering industry	205	343	790	1,345	1,646
Building materials industry	194	297	525	830	850
Chemical industry	238	454	1,502	3,368	3,821
Light industry	185	261	442	647	690
Food industry	181	218	393	581	650

Table 6.1: Historical Industrial Sectors

diffused from non-point sources, such as improper and extensive industrial refuse distribution (i.e., dumping), from traffic which deposits emissions in water, and from agricultural chemical transference from sites of application. Industrial dumping (as well as agriculture chemical seepage) has resulted in complete destruction of the subsoil water source. Contamination of this water layer has occurred mainly bacteriologically or by the presence of nitrates [59].

The integration of environmental considerations into industrial policy and planning is a relatively new concept. Until recently, most industries continued expansion without regard to the quality of the environment. The most environmentally hazardous industries are those extracting products from raw materials. The extraction of hydrocarbons from coal during the mining process has become increasingly concentrated in the central and southern part of the Great Plain. Metallurgical works and power plants generate great quantities of wastewater (Table 6.2) in addition to SO_2 and solid particulates (as does the cement industry).

The chemical industry produces the most diversified types of pollutants, including gaseous substances, acid and alkali wastes, solid pollutants, pigments, solvents and toxic solutions. The chemical industry in Hungary is located along the main waterways of the Danube and the Tisza Rivers, thereby directly effecting the ecology of the Great Plain.

The food industry is the greatest producer of organic wastes, which most often contaminate both the soil and the water. The greatest polluter of water however is the paper and cellulose industry. Hungary's most polluted areas (which cover 10% of the total land area), are, coincidentally enough, in its most industrialized zones. Pollution affects 40% of the population, due to concentrated demographics in the industrialized complexes and urban areas.

	Sources, numbers	*Waste water millions of m^3*
Mining and quarrying	81	82
Electric energy	23	2,563
Metallurgy	13	59
Engineering	195	54
Building materials	95	9
Chemical industry	50	110
Light industry	106	57
Food industry	540	38
Other industry	65	0
Industry total	1,168	2,972

Table 6.2: Industrial Generation of Wastewater

INDUSTRIALIZATION IN ARIZONA

In Phoenix, turf-related facilities, dairies, sand and gravel operations, and electric power generating facilities account for over 80% of industrial water demand. In 1985, the actual industrial water use was 7,823 hectare-meters. Industrial users also have the right to withdraw up to 19,123 hectare-meters $year^{-1}$. Increased industrial water demand is tied to projected population growth estimates. Industrial water use accounted for approximately 3% of the total water demand in Phoenix in 1985. However, industrial production levels and water use fluctuate with varying economic conditions.

According to the 1987 census of Arizona manufacturers, the three largest manufacturing sectors were (listed in order of prevalence) printing and publishing, machinery (other than electric), and fabricated metal products (Table 6.3). These industries in Arizona exert the same polluting effects as those in Hungary. Industry is responsible for water pollution involving the presence of heavy metals and Volatile Organic Compound (VOC) contamination, resulting from improper disposal of industrial solvents, degreasers, and other organic compounds. The above-listed contaminants can be found in groundwaters near semiconductor facilities in Phoenix, Scottsdale, Mesa and at Williams Air Force Base in Chandler [6]. The VOC most commonly found is trichloroethylene (TCE), an industrial solvent. VOC contamination is present in groundwater at several sites within the sub-basin; many of these sites are associated with small sources such as dry cleaning stores and leaking underground storage tanks. Groundwater is also contaminated with boron, methane and chloroform. Also identified within the Phoenix Active Management Area (AMA) is soil contamination by acids and

Industry Group	No. of Firms	Payroll	Value Added by Manufacturer
Electric, Electronic Equipment	**249**	**$ 808,100**	**$2,007,300**
Electronic Components and Accessories	133	640,100	1,824,000
Communication Equipment	23	D	D
Machinery, Except Electric	**578**	**571,700**	**1,419,900**
Office and Computing Machines	43	355,800	997,800
Refrigeration and Service Machinery	40	36,600	86,400
Transportation Equipment	**148**	**1,056,500**	**2,469,400**
Primary Metal Industries	**57**	**185,500**	**617,400**
Nonferrous Rolling and Drawing	15	118,800	414,000
Printing & Publishing	**883**	**305,600**	**861,000**
Newspapers	117	140,500	403,800
Commercial Printing	554	102,600	196,000
Food & Kindred Products	**176**	**160,700**	**655,500**
Beverages	21	46,000	138,200
Fabricated Metal Products	**390**	**169,000**	**326,400**
Fabricated Structural Metal Products	179	96,600	168,400
Instruments, Related Products	**131**	**477,300**	**943,400**
Measuring and Controlling Devices	65	103,100	218,200
Stone, Clay, Glass Products	**271**	**183,600**	**506,200**
Concrete, Gypsum, and Plaster	172	147,800	400,300
Chemicals & Allied Products	**95**	**71,100**	**393,000**
Rubber, Miscellaneous Plastic Products	**163**	**94,500**	**234,600**
Lumber & Wood Products	**292**	**130,800**	**264,000**
Millwork, Plywood, and Structural Members	146	63,700	129,100
Other Industries	**215**	**67,100**	**196,700**
Toys and Sporting Goods	30	35,500	126,200
Signs and Advertising Specialties	62	13,500	25,500
Apparel, Other Textile Products	**156**	**55,200**	**116,700**
Paper & Allied Products	**33**	**42,400**	**144,300**
Furniture & Fixtures	**173**	**48,400**	**96,500**
Household Furniture	78	26,900	52,500
Petroleum & Coal Products	**18**	**5,200**	**21,700**
Leather, Leather Products	**26**	**4,700**	**11,200**
Textile Mill Products	**19**	**5,200**	**14,000**
Auxiliaries	**78**	**226,900**	**-**
TOTAL	**4,151**	**$ 4,669,000**	**$ 11,299,000**

Table 6.3: Industries in Arizona

cyanide from several industrial facilities.

Disposal of industrial solvents has been documented since the 1950's. Industrial waste disposal practices have included injection into dry wells and disposal into surface impoundments, leach fields, dry washes, and unregulated landfills, all of which lead to groundwater contamination. Public drinking water wells in Phoenix and Tucson have been closed to to VOC contamination.

The mining industry in Arizona has significantly contributed to water pollution. Heavy metal contamination has been associated with mining sites, as have radioactive elements. Copper smelters and coal fired power plants contribute aresenic through atmospheric deposition of arsenic in rivers and lakes. Petroleum hydrocarbons from leaking underground storage tank sites are a significant source of groundwater contamination. The City of Phoenix refueling facility has lost a documented 500,000 gallons. The free product pool on the water table of this amount is 1,500 feet. The maximum contaminant level for benzene is 5μg/l. At this site benzene concentrations reach 2,200 μg/l. There are also several thousand gallons of sp-4 jet fuel floating as free product on the water table on the Williams Air Force Base. The benzene concentration in this area is 24,000 μg/l.

Industries in Phoenix use groundwater primarily for commercial turf watering, landscape watering, processing, and cooling. The Groundwater Code defines industrial use of water as "non-irrigation use of water not supplied by a city, town, or private water company, including animal industry use." Industrial facilities supplied by their own wells are classified as industrial users. Approximately 16% of groundwater withdrawal is used in industry primarily by cooling, landscaping, sanitary and kitchen requirements, and water used in the industrial processes themselves. Various types of commercial and manufacturing water uses are also included in this category such as construction uses, nurseries, stock-watering operations, and institutional uses including those of hospitals and schools.

CHAPTER 7:

WATER RESOURCE POLICY ANALYSIS IN HUNGARY AND ARIZONA

WATER RESOURCE POLICY ANALYSIS IN HUNGARY

Various aspects of environmental protection have been legislated since the 18th Century in Hungary. These include protection of the natural environment (from negative anthropogenic influences), protection of specific ecosystems or terrestrial environments from natural erosion, subsidence and alkalization, and protection of urban and suburban environments from noise, water and air pollution [37]. After World War I, and the fall of the Austro-Hungarian empire, environmental protection lost conceptual importance. It was not until 1935 that Parliament once again began initiatives toward environmental legislation. Although advances were slow, World War II impeded the advancing progress of environmental law.

In 1964, the Act on Water Management was enacted, and by 1971 the term "environment protection" appeared in Hungarian law [37]. By April 1972, a public movement began in which there were protests of the increasing environmental contamination that was occurring due to population growth, urbanization, and unrestricted industrialization. This protest culminated in Act II 1976 on the Protection of the Human Environment. Section 9 of the Act specifically called for protection of water resources.

Since its induction, the Act has been amended particularly in relation to its water resources legislation [37]. Penalties for pollution of rivers and lakes experienced re-regulation in both 1978 and 1984, and penalties for sewerage water pollution exceeding specific limits were also updated in 1984. A system of fines is in force for the unlawful disposal of untreated sewerage into certain surface waters, for the improper disposal of hazardous waste, and for discharging hazardous effluents into storm drains and sewer inlets above already-identified specific limits. It became apparent in the 1980's that the state of the Hungarian environment must be listed as a social and economic priority. Unfortunately, this emphasis lost some of its strength in the wake of the great socioeconomic transition of the past few years [37].

The Ministry of Environmental Protection and Water Management began in December 1987. This Ministry functions (amongst other things) in coordinating all international activities related to water management, inclusive of signing treaties and conventions. This is a highly important function due to Hungary's international character of water resources; 95-95% of surface water supply comes from other countries. It is of the utmost importance that clean water acts be signed with counties upstream to Hungary. Multilateral agreements between Hungary and other countries (particularly neighboring countries) are one of the key features to ensuring a good water quantity and quality supply. Agreements that have already been made must be reviewed and potentially updated, due to the fact that some of them date back 50 years.

The 1980's marked the advent of two important multilateral agreements. The first, "Declaration on the Cooperation of Countries Lying Along the Danube in the Field of Water Management, Especially on Pollution Control of the Danube River" was signed in 1985. In this signed agreement, eight countries along the Danube's catchment area agreed on a plan for regional solutions to water issues relative to this region. Included were issues addressing water quality management, water balance, and flood prevention and control. Under this agreement, Hungary is responsible for developing flood prevention and control strategies.

The second multilateral agreement was signed in 1986 by five countries and is entitled "Convention on the Protection of the Water of the Tisza River and its Tributaries". This agreement mandates all signatory countries to take whatever technical and economic measures are necessary to reduce pollution loads to the Tisza River, as well as its tributaries.

Many international cooperating organizations work closely with Hungarian officials. Included on this list is the United Nations Economic Commission for Europe, the World Health Organization, UNESCO, and the World Commission on Environment and Development.

WATER RESOURCE POLICY ANALYSIS IN ARIZONA

In some areas, the lack of viable water supplies has caused the governing bodies of the State of Arizona to create supplies by funding and building projects. In other areas, the lack of a dependent water supply has significantly limited economic growth and populous expansion due to the lack of financial commitment to water resource development in that particular area. Therefore, Arizona has made determinant, chosen commitments as to the geographical areas which will receive the resources for advancement. In addition to the development of water projects (as well as the induction of new governmental agencies to oversee implementation and operating management issues), new rules governing all aspects of water use have been inducted.

As water resource issues have expanded with increasing development, so has the complexity of the reource management area. The Central Arizona Project (CAP) is a prime example of the cost and complexity interaction of many levels of government for the purpose of managing water supplies to meet the increasing water demands. A new governmental agency, the Central Arizona Water Conservation District (CAWCD) was formed to manage delivery of water to providers of CAP. In addition, nine irrigation districts were formed to contract and sell water to their landowners.

The rules and management of water surfaces varies with the type of water. The use of surfacewater is managed differently if it is federally developed interstate water (such as CAP water) or appropriable water such as water from the Little Colorado River and Gila River. Groundwater was relatively unmanaged until 1980. Although large geographical areas were experiencing overdraft in the 1940's, effective management did not begin to appear until the 1970's when the first Statewide Water Resources Inventory explained the threat of long-term depletion of groundwater on the continued economic development of Arizona. In 1978, the Arizona State Legislature created a Groundwater Management Study Commission to consider the best method to manage long-term groundwater supplies in Arizona. The Commission recommened that groundwater depletion should be reduced to safe-yield levels through mandatory conservation programs in urban and agricultural areas of the state in order to preserve the long-term economy of Arizona. The Commission passed the recommendation for the four AMA's in 1980.

In addition to interstate water resource issues that are on the agendas of state water resource managers, there is also the presence of international water issues due to Arizona's borderstate status. The Mexican Treaty of 1945 involved allocating 184,500 hectare-meters of Colorado River System water annually, to be increased in years of surplus to 209,100 and also to be reduced proportionately during years of extraordinary drought. The Treaty dealt with quantity and stated nothing of the quality of water to be delivered across the border.

In 1962, the Mexican Government raised a formal protest against the United States Government regarding the quality of Colorado River water that was being delivered to the Mexicali Valley. The State Department requested that the governors of the seven Colorado River Basin States reconstitute the Committee of Fourteen (two water experts from each of the seven Basin States appointed by the governor) and provide advice on the Mexican water salinity problem to the State Department and to the International Boundary and Water Commission.

Adoption of Minute 242 (which was executed in 1973) obligated the

United States to implement measures that will maintain the salinity of the Colorado River waters delivered to Mexico at nearly the same quality as that diverted at Imperial Dam for use within the United States. To accomplish this, four desalting plants were constructed to maintain salinty levels. The Act also authorized construction of a large well field along the border south of Yuma to prevent Mexico from drawing large quantities of surface and groundwater from the U.S. via an existing large well field operated by the Mexican Government.

In 1968, the Colorado River Basin Project Act authorized the CAP (as well as other water development projects in the Upper Basin). The Central Arizona Project was designed to provide the conveyance and storage facilities necessary to import a major portion of Arizona's remaining share of the Colorado River water into the south-central part of the State. Section 301 (b) of the Act provides for allocations of water to California and Nevada, as well as Arizona. Contracts for CAP water must contain provisions to control expansion of groundwater use for irrigating in the contract service area.

This Act also declared that the satisfaction of the requirements of the Mexican Water Treaty from the Colorado River constituted a national obligation which shall be the first obligation of any water augmentation project planned pursuant to the Act and authorized by the Congress.

Several Federal management agencies have imporant (direct and indirect) influence on water resource issues in Arizona. The U.S. Department of Interior oversees several of these agencies. For example, the Bureau of Reclamation, an agency that has made the most significant contributions to water supply in Arizona. The agency designed and built Hoover Dam and Power Plant, Glen Canyon Dam and Power Plant, Parker Dam and Power Plant, Davis Dam and Power Plant, the Salt River Project, Gila River Project, and

CAP. The Bureau continues to be an important force in water management issues in Arizona through its administration of the Colorado River Basin Project Act and the contractual agreements for the use of CAP water.

The U.S. Geological Survey (of the U.S. Department of Interior) gages streamflow and (partially) funds groundwater monitoring programs which are performed by the ADWR. The agency also conducts scientific analysis of water availability and movement within Arizona. The Fish and Wildlife Service is responsible for preparing and reviewing environmenal impact statements and administration of the endangered species act. The Bureau of Indian Affairs oversees all Indian trust lands. And the Bureau of Land Management and the National Park Service manage over 6, 885, 000 hectares of land.

The U.S. Department of Agriculture (USDA) oversees several agencies that involve water resources management. The Soil Conservation Service and Agricultural Research Service both have research and development programs centered on water conservation management. The Soil Conservation Service has built several flood control structures in Arizona. The Forest Service manages large areas of land that include plans for watershed managment criteria designed to protect and enhance runoff.

The U.S. Environmental Protection Agency implements federal water quality regulations on water supply planning. National programs for groundwater protection, development of water quality standards for surface water streams and drinking water, and toxic cleanup programs are all adminstered by this agency.

State law is administered differently, depending upon the type of water: surface- or ground-water. The State government adjudicates rights to surface waters, which, except for Colorado River water, are subject to the doctrine of prior appropriation. Based on the tenet "first in time, first in right", appropriated water in Arizona must be beneficially used and its use must be appurtenant to the land. Groundwater management is under the already described Active Management Areas. These established areas are overseen by the ADWR. Many issues affect the distribution, cost, quality, quantity, and use of water in Arizona. These issues range from legal issues, such as the ongoing adjudication of the State's surface waters, to international border issues and water quality issues. All water resource issues are interrelated in some way. For example, water quality problems in Arizona could be due to discharges of sewerage or mine wastes in Mexico. Arizona's present water issues can be grouped into water supply planning (of which groundwater overdraft is of the utmost importance), environmental and quality, and adjudication of interstate and border issues.

Agricultural, municipal, and industrial use of groundwater has seriously depleted some aquifers, particularly those within the AMA's. A significant amount of groundwater under the Phoenix metropolitan area has been withdrawn and not replaced. Statewide, groundwater is the primary source of drinking water for small water companies and for agricultural use. Overdraft will continue in the non-AMA planning areas as cities and towns with no renewable water supplies continue to overdraft groundwater. Due to the fact that there does not appear to be a practical, affordable alternative, in many cases, to overdrafting groundwater, this problem is expected to continue.

Overdraft of groundwater is interrealted to most other water resource planning issues in the State. Water quality is adversely affected as increasing amounts of solids are dissolved in decreasing amounts of water in aquifers. Riparian areas have diminished in size or have even become extinct. When Arizon'a allotment of Colorado River water is fully exhausted, no new or renewable supplies are expected to be available. Therefore, Arizona's groundwater is and will continue to be an important resource for the State. Effective "conjunctive use" (described below) and wise management of groundwater are considered to be essential for a dependable future supply.

Water quality issues can be classified into natural groundwater contamination (such as metal deposition from aquifer material or the underlying bedrock), man-caused groundwater contamination (such as the presence of VOCs, nitrate, sulfate, pesticides, and bacterial contamination), and man-caused surfacewater contamination (radioactive wastes from mine tailings, metals from effluent and mining wastes, and pesticides). Groundwater contamination remediation is often not practical or not cost-effective. Standards for treated wastewater (effluent) are becoming more stringent, therefore the cost to city wastewater treatment plants will increase at a highly significant level in the future.

Most interstate water issues have historically involved apportionment and use of the Colorado River water, therefore it is projected that the majority of the future issues will be of the same nature. Some rivers arise in other states and flow through Arizona to meet rivers in another state. The Virgin River in northwest Arizona, for example, arises in Utah, flows through Arizona and meets the Colorado River in Nevada. Arizona is dependent on the Virgin River's waters for agricultural irrigation, and has therefore begun to express concern for diversions that are occurring upstream in St. George, Utah. Nevada also has concerns about the potential for increased diversions and groundwater pumping in Arizona. Water-intensive industries have been planned for Nevada near its border with Arizona. These proposals have raised concerns that surface- or ground-water that could be used in Arizona will instead go to Nevada for use.

Formal agreements and interstate coordination will be mitigated in the future to solve these water supply issues.

Water resource issues along the Arizona-Sonora Mexico border have been important for many years. Most discussion (and conflict) has centered on the Colorado River, however, issues involving other surfacewaters, groundwater, and water quality have also arisen. The U.S.-Mexico Treaty of 1945 and other agreements have governed the quantity and quality of Colorado River water which is delivered to Mexico.

Pumping of groundwater near the international border has been an issue for many years. The United States Government and the Mexican Government have agreed to limit groundwater pumping along the border in an effort to maintain historic water gradients in the area. However, large-scale agricultural areas in northern Sonora (Mexico) use large amounts of groundwater. In Nogales, unrestricted flows of sewerage containing hazardous waste have flowed in Nogales Wash northward from Mexico into Arizona in recent years. Arizona has placed a chlorination facility in the wash as an interim remedy. The Nogales International Wastewater Treatment Plant needs to be expanded to accomodate flows.

Livestock and other farming operations in Mexico contribute to increased nitrate levels in the San Pedro River as it flows northward into Arizona. Cooperative efforts by the United States and Mexico will need to be attempted in the near future to begin solving these discrepancies. Mexico has historically cited lack of funds as a reason for many of the problems.

While maintenance of minimum flows across the border from the U.S. to Mexico historically have been a source of concern on the Colrado River, no agreements govern the flows for rivers flowing into the U.S., such as the San

Pedro River and the Santa Cruz River. Although increased diversions, groundwater pumping and poor quality discharges may have adverse impacts on the water supplies in Arizona, few stream measurements or water sample analyses are available to predict the magnitude of future problems. Water agreements for such streams may be necessary in the future.

CHAPTER 8:
NEW RESULTS

The geographical position of both Hungary and Arizona exemplifies the international character of global environmental problems and the need for international cooperation. Environmental problems such as drought, flood and waterlogging as well as grassland deterioration, soil erosion and desertification (all of which are related to climate change) restrain the sustainable development of land use in each region. Therefore, climate protection and adaptation to climate change are very important to the further development of both areas. No single government is in a position to master global environmental problems, technical co-operation and transfer of knowledge and environmentally sound technology are highly important to Arizona and Hungary. The principle of prevention must also be applied in the international environmental policy arena, since remedial action is more costly and less effective than prevention and the targeted control of root causes.

In the context of increasing frequency and intensity of droughts, it is expected that the entire structure of production must be changed. This will require costly investments, however, revolving environmental funds are possible to establish. The "polluter pays principle" is of the utmost importance to initiate the revolving funds plan. Additionally, German Chancellor Helmut Kohl has stated that his country is committed to financially assisting regionally developing countries. This is in an effort to accomplish his stated goal of furthering the progress of the initiation of these countries into the European Economic Community.

Although the details of future climate change cannot be predicted with

100% accuracy, certain broad trends are considered probable as the result of altered atmospheric composition. These trends are identified below.

The Great Plain has a large percentage of loess that has formed by wind. This soil will continued to become eroded if afforestation does not occur. Additionally, the loess loam has become altered into alkali soil in some places on the Plain. Alkalization will take further advantage of this already preceding process if measures against desertification are not accomplished. It is also worth mentioning that the continental character of Hungary will set the stage for stronger solar radiation than in western Europe. It is positive that the some of the very hot and dry east wind that blows over Ukraine and Romania in the summer is diverted by the Carpathian Mountains. If this were not the case, desertification would be furthered at an even faster rate on the Great Plain. On the contrary, one must still remember that the maximum amount of sunshine received in Hungary is on the Great Plain, thus enhancing the rate of desertification.

The Basin and Range Province of Arizona contain many silt and clay hydrogeologic units. These are predictably susceptible to wind erosion. Waterlogging can also be predicted to increase in the Centennial Wash Area due to the cones of depression that have formed there. If groundwater withdrawals do not tremendously cease, this trend will continue, eventually giving rise to increased saline soils.

As has been repeatedly stated, human economic and political systems - the means of earning a livelihood and of self-government - have been unable to cope with recent climatic fluctuations. Hazards that would have been easily absorbed in earlier times now threaten the livelihood, and even the lives, of thousands. If desertification is to be brought under control, it is imperative that human societies relearn what they first learned thousands of years ago - that they can prosper in the arid zone only if they can survive its harshest threats and devise an economy in harmony with nature.

CHAPTER 9:
RECOMMENDATIONS FOR SUSTAINABLE FUTURE PRODUCTIVITY

INTRODUCTION

To devise an economy that is in harmony with nature requires more than technological "fixes". Land-use control is the key to maintaining healthy and productive regions. Applied climatology and ecology must go hand in hand with policy formation in seeking this harmony. Geomorphological information has probably not been applied to the needs of environmental policy formulation to the extent that it could. This is especially true in Arizona (as well as the United States as a whole) due to the extreme lack of emphasis on geology and (especially) geography within educational system and society as a whole.

Planning is concerned with the physical development and use of land. It is thus clear that geomorphological and other earth science information can be an important element both in the formulation of planning policies and in the determination of individual applications.

The following recommendations for each region are given in conclusion as a means to either prevent or reverse the problems outlined in this text.

HUNGARY

- Improve long-range drought forecasting, coupled with social and economic infrastructure to use the forecasts
- Develop a state wide environmental data bank in accordance with the outlined macroregions of the country
- Prevent further soil erosion either by contour ploughing or planting or constructing windbreaks
- Increase the quality of irrigation management
- Stabilize moving sands by reestablishment of plant cover
- Increase the use of integrated remote sensing, Geographical Information Systems (GIS), and other systems in cataloguing and evaluating natural resources data from drylands
- Increase cultivation testing of low-water use plants for establishment of ground cover (for example, jojoba, creosote, and acacia)
- Involve prisoners of the criminal justice system in recycling programs with the goal of decreasing landfill occupancy
- Preserve forests in the north so that evapotranspiration is carried to the interior of the country
- Induction of an economically-driven plan in which all water resource consumers partake (inclusive of paying for domestic water use)
- Establish water use meters for all individual domestic units
- Involve the public in attention to water use issues and the cost commodity of water
- In the wake of new industries in the country, limit the establishment of polluting industries or those that do not strictly follow the environmental regulations of the government
- Initiate volunteer-collected data programs
- Strictly follow the "polluter pays" principles

- Establish a permit system for water resources and only allow those on a "first come, first serve" basis

- Limit subsoil compaction via heavy agricultural mechanization

- Further the testing of biocontrol methods to replace agrochemicals

- Increase international conferences and exchange of environmental data

- Enhance the environmental curriculum of higher education

- Educate the general public, especially children through children's school and television programs

- Bring the issues of sustainable land use and development to the public by advertisement

ARIZONA

- Limit vehicular emissions since the increase in temperature of the region can be directly correlated

- Store excess surface water through recharge during "wet" periods to replenish the aquifers

- Limited the number of imported plants, such as the salt cedar

- Increase the percentage of desert vegetation in residential and municipal landscaping

- Eliminate effluent discharges into productive areas

- Increase the quality of irrigation water

- Conduct further soil tests to characterize the nature and distribution of DDT and toxaphene in the Phoenix area

- Mitigate above-ground chemical storage leaks and spills

- Expand the guidance levels for DDT and toxaphene to consider risks from inhalation exposure
- Improve long-range drought forecasting, coupled with social and economic infrastructure
- Increase in-stream monitoring
- Continue volunteer-collected data programs
- Further the testing of biocontrol methods to replace agrochemicals
- Increase the environmental education of the general public
- Bring issues of sustainable land use and development to the public by advertisement

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